MODERN
ELECTRIC
PRACTICE

MODERN ELECTRIC PRACTICE

Prepared under the Editorship of

MAGNUS MACLEAN M.A. D.Sc.
PROFESSOR OF ELECTRICAL ENGINEERING IN THE GLASGOW AND WEST OF SCOTLAND TECHNICAL COLLEGE

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Section III

(*Continued*)

Electric Traction

3. Overhead Construction

CHAPTER I

HISTORICAL AND GENERAL

The use of overhead wires for the transmission of electrical energy to a motor or motors on a tram-car was first introduced about 1883, and tramways were operated by this method in both the United States and Germany The wires were supported on J-shaped hangers and the trolley wheel or wheels ran on top of the wire In some cases one wire was used with a rail return, and in others two wires, a few inches apart, upon which ran a small trolley usually with four wheels The current in all cases was conveyed to the car by a flexible cable which pulled the trolley along on the wires

Daft and Vanderpoel were the earliest workers in this line in the United States, and Siemens on the Continent.

This method of transmission was found open to many objections it was troublesome and unreliable, and was superseded by the under-running trolley system, with the arched form of suspending device at the curves, now in general use This appears to have been used by Sprague and Vanderpoel in 1887–88

The earliest types of insulator for the under-running trolley were the ordinary porcelain spools at each side of the curve hanger, and a small wooden block with a canvas petticoat for a straight-line hanger, the block of wood being provided with a hook at each end for attachment to the ear and span wire

About 1889 the moulded insulator, composed of powdered asbestos or mica and some cementing compound, hydraulically pressed to the required shape, came into use It was soon found that this type of insulator needed protection from the weather, and by 1890 what is generally known as the "West End" type of hanger was developed (fig 942). This principle, with slight modifications as to shape of bolt and petticoat and method of locking the cap, may be considered the standard practice of to-day.

The first poles used were of wood, and the span-wire system of support was most generally used, although there are some early examples of a bracket method of support, bracket and poles both being of wood.

In 1889 steel poles were first used, and secondary insulation became necessary. This was obtained by means of a hardwood plug 15 inches

long driven into the top of the pole and provided with a cast-iron cap to shed the water (fig 919) This method of secondary insulation was used for several years, and was superseded by the present method of an iron-pole strap holding a strain insulator

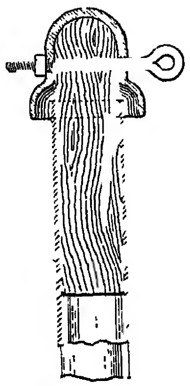


Fig 919—Section of Top of Steel Pole, with Hardwood Insulator

From the above it will be seen that overhead construction in its present form dates from 1890–91 The first overhead trolley line built in England was constructed by the writer in 1891 at Leeds.

The earliest types of overhead switching devices, or frogs as they were called, were of the mechanically-worked variety, but very cumbersome and unreliable With the introduction of the under-running trolley it was found possible to devise a frog which, if placed in the proper position, would run automatically in any direction with a high degree of certainty This type has become universal throughout the United States, and has been largely used in England and on the Continent.

In 1892 the side-running system of trolley was introduced on the South Staffordshire tramways, and was received with favour by the

Fig 920—Span-Wire Construction

English municipal authorities, more perhaps on account of the absence of span wires than any inherent merit in the system

Preference for this system on the part of the local authorities was so strong that engineers turned their attention more particularly to it,

and have improved, developed, and removed its earlier defects, and it may now be considered the standard English practice

General Considerations.—The overhead system may be divided into the following classifications:—

1. Span-wire construction (fig. 920), adaptable to practically all possible conditions of working

2. Bracket suspension, subdivided into (1) centre-pole and double-bracket (figs 921 and 922), and (2) side-bracket construction (fig. 923). The former is only applicable to double track and wide streets. The latter may be arranged with brackets on one side of the street, suitable for comparatively narrow streets, or on both sides, applicable to fairly wide streets

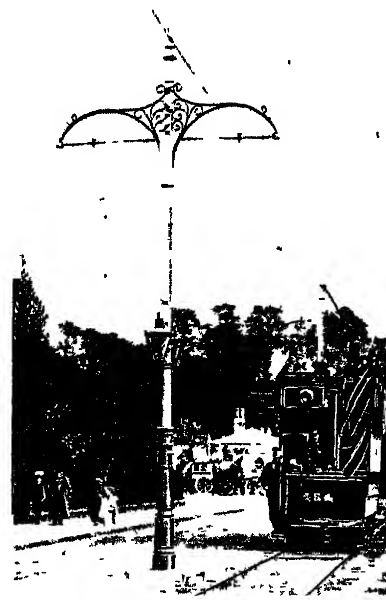


Fig 921 —Centre-Pole Construction Double Bow-String Bracket

Another general classification may be made of lines constructed for the centre-running trolley and for the side-running trolley. In the former case the trolley head is rigid (fig. 924), and the trolley wire follows as nearly as possible the centre of the track, the deviations from the centre line allowable not being more than a couple of feet

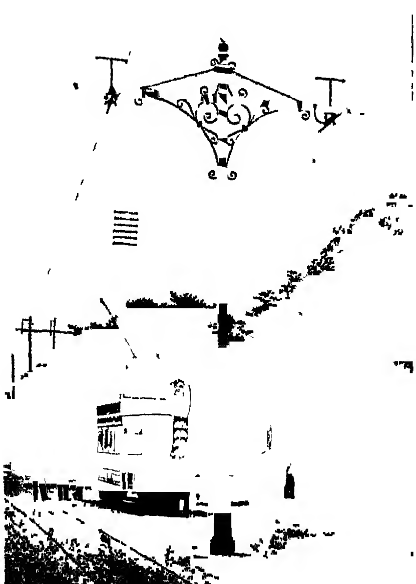


Fig 922.—Centre-Bracket Construction Rigid arm

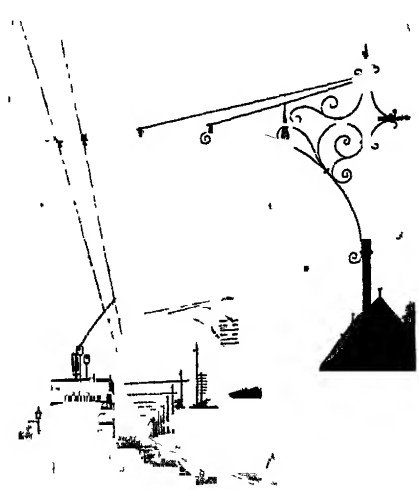


Fig 923 —Side-Bracket Construction. Rigid arm

For the side-running trolley, the trolley head is pivoted so that it can turn completely round (figs. 923 and 925), and in this case the trolley wire need be only approximately parallel to the track and as far from the centre as the length of the trolley arm will permit.

Choice of System.—In laying out an overhead system the first point to be determined is the desirability of using mechanically-moved or fixed frogs, this point determining which type of trolley can be used

Fig 924 —Harp for Rigid Trolley Head

If the fixed frog is decided upon, it necessitates the use of a centre-running trolley with a rigid head If the mechanically-moved frog is considered most desirable, the centre-bearing trolley can be used, but it is preferable to employ the side-bearing trolley with its greater allowable variations in the relative positions of track and trolley wire This enables the number of pull-off wires and insulators to be reduced to a minimum.

The mechanical frog is much more reliable than the fixed frog, and if properly designed and set, presents no greater probability of the trolley leaving the wire than straight track It, however, necessitates a separate attendant to set it for the desired direction, otherwise the conductor or driver must leave his post in order to set it The former entails annual expenditure, the amount of which depends upon the number of branch lines to be operated, and the latter delays the car while the frog is being set

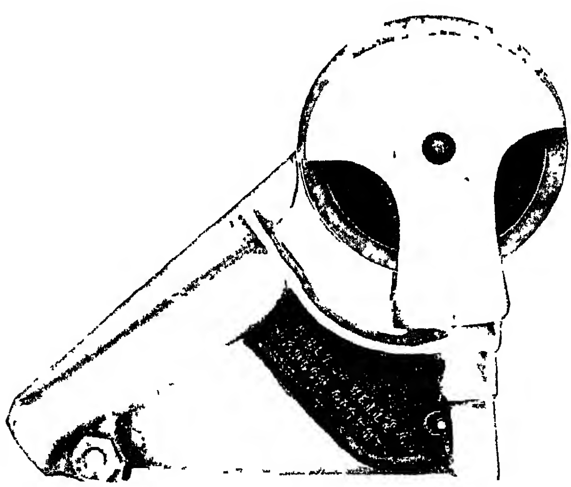


Fig 925 —Swivel Trolley Head

If the street is of sufficient width to allow the use of the centre-pole form of construction this delay will be negligible, but if it is necessary to place the poles on the footpath the delay would be considerable, and in a street having heavy vehicular traffic it might be serious This would also mean expense to the tramway and inconvenience to passengers As junctions usually occur in more or less busy places, working the frogs would seriously interfere with a conductor's duties, and it is always extremely bad practice to have a driver leave his post

Therefore a mechanical frog will in most instances necessitate an attendant, and as tramways usually work from 16 to 18 hours a day, it would require the services of two men at each junction As against this, the working of the mechanical frog is so reliable that the con-

ductor can tie up the trolley cord and give his entire attention to the collection of fares. Owing to the short distances that many passengers are now carried this is an important advantage.

The fixed frog at simple junctions can be made to work with very nearly the certainty of the movable frog, but not to the degree of tying up the trolley cord before-mentioned, and it is always necessary for the conductor to watch the trolley with some care at junctions. If the junction is very complicated the fixed frog is at a great disadvantage, for no matter how carefully and accurately the frogs may be set, the unequal strains caused by the expansion and contraction of the adjacent wires very frequently throw the frogs out of adjustment. Therefore, except under special circumstances, the balance of advantage seems to be on the side of the mechanically-moved frog

The next point to be determined is whether the centre-bearing or side-bearing trolley is to be used

If the system of tramways consists of fairly straight routes, and the centre-pole or span-wire construction can be used throughout, or side-bracket construction on single track with streets not over 30 feet between the kerbs, and if æsthetic considerations are not of the first moment, the centre-bearing trolley with the rigid head will probably be quite satisfactory. But in any case where double track is used and the centre-pole construction is not possible, where streets exceed 30 feet in width, or where span-wires are objected to, the side-running trolley, having a greater degree of flexibility, will be found the most serviceable

The side-running trolley has the very marked advantage of being able to work with the trolley wire 12 feet or even 15 feet from the centre of the track, and to get around curves with very few pull-off wires, but it must be remembered that it is not good policy to continually strain these valuable features to their limit

It may be taken as a principle that the closer the trolley wire is to the centre of the track the better it will work, and the writer believes that the trolley wire should not be farther than 6 feet from the centre of the track, unless there are special local reasons for exceeding this distance This distance can be worked very nicely with a 12- or 13-feet trolley arm, which is a standard length; a greater length of arm very materially increases the strain on the trolley standard and car roof at points where it is difficult to increase the strength

It is also not advisable to reduce the pull-offs at the curves to their absolute minimum, as, although the swivel-head trolley will take a very sharp angle, the sudden change of direction tends to make the wheel leave the wire if anything about the trolley wheel or stand is not in perfect condition And there is also some danger, with very sharp angles, of putting more strain on a single insulator than it can be constructed to bear. This will lead to failure of the insulator, which, on account of the heavy strain, would be very troublesome to replace.

The type of construction to be used at different points of the system will next require consideration.

Of the several types — span-wire, centre-pole, and side-bracket — the

span-wire is undoubtedly the best from a mechanical stand-point and as regards smoothness of working. This system is applicable to every width of street and to practically all conditions of service The sole objection that can be raised against it is on æsthetic grounds, but the English authorities have shown such a strong prejudice against this type of construction that it is used in but comparatively few places.

In some cases span-wires are erected without the use of poles, by attaching the span-wires to fixtures (figs 926 and 927) bolted to the fronts of buildings along the route. This is a very satisfactory method of construction, as it embodies all the good features of the span-wire system

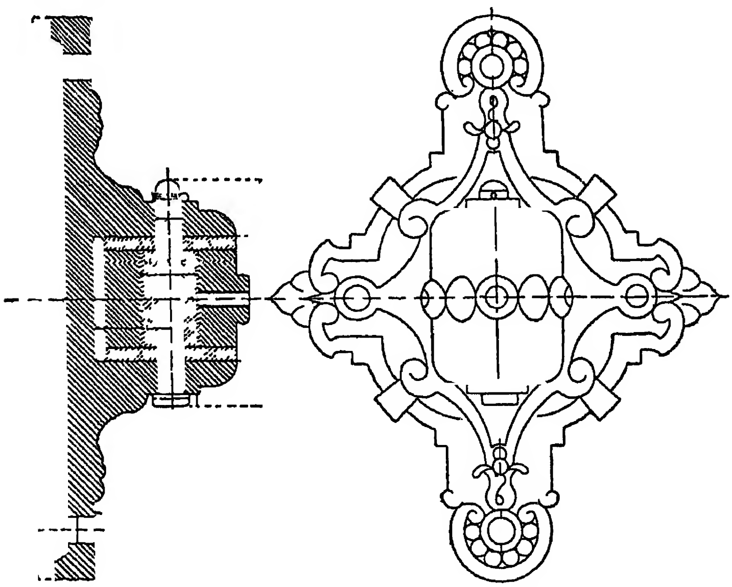


Fig 926 —Section and Elevation of Rosette Large

and is the least conspicuous form of overhead construction that has been devised.

It is not easy, however, in practice to use this to any large extent, owing partly to the difficulty of obtaining the consent of the property owners and partly to the difficulty of finding buildings of sufficient strength to carry the span-wires. Suitable buildings are most often found along the business streets of a city, which are in many instances wide enough to accommodate a double line of tramways with centre-pole suspension.

This centre-pole and double-bracket form of construction is one of the most popular, and is generally used where circumstances will permit, and lends itself to ornamentation, particularly when used in conjunction with electric lighting, better than any other method. And with its short brackets, bringing the trolley wire close to the centre of the track, is, when flexible suspension is used, mechanically second only to the span-wire In some cases very short brackets have been used,

bringing the trolley wires only 2 or 3 feet apart, but this renders it difficult to get a flexible form of support for the insulators, which is essential to smooth running.

The side-bracket construction is in most instances the least desirable from a mechanical stand-point, but has been very largely used. The brackets vary in length from 3 to 25 feet. Brackets of such great length as the latter should be avoided when possible, as they are difficult to construct of sufficient strength, are expensive, and have nothing in their appearance to recommend them.

With brackets placed at the usual height, 22 feet from the kerb, a length of 8 to 10 feet is the proportion most pleasing to the eye, and anything beyond about 16 feet begins to look top-heavy. A 16-feet

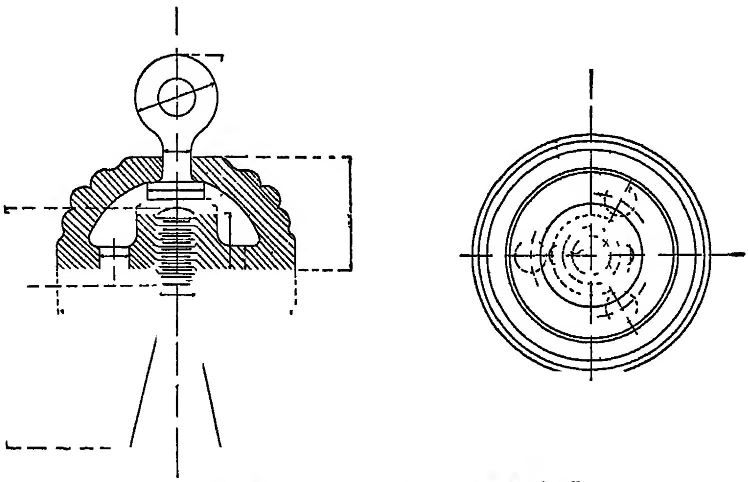


Fig 927—Section and Elevation of Rosette Small

bracket will give 14 feet of effective length from the kerb to the trolley wire, and by adding to this the 6-feet reach of the trolley arm previously referred to, the total reach is 20 feet, which would enable a single track to be worked from the centre of a 40-feet street. This is about as wide as will often be met with in English practice

In the case of a double track these lengths will work up to a 32- or 33-feet street, and if a greater width of street was available the centre-pole form of construction would probably be used In many cases the width of the street will be found to vary very considerably, and as it does not look well to put in a few centre brackets here and there, it may sometimes be necessary to use brackets of exceptional length Or, as an alternative, side-bracket poles may be placed on each side of the street.

This form of construction may be somewhat expensive owing to the extra number of poles and brackets required, but the appearance is good, and it obviates the necessity of excessive length of bracket and excessive reach of trolley arm, and can be operated in a street 50 feet wide without materially exceeding the above-mentioned limits.

CHAPTER II

MATERIALS

Poles.—Numerous types of poles have been tried, but the tubular steel pole has now become standard practice

There are three types of tubular steel poles, the first and most largely used consists of three lengths of pipe of various diameters, telescoped into each other, the sections of pipe being either solid-drawn or lap-welded

The usual practice in making these poles is to use pipe varying in diameter about 1 inch between each of the sections. The larger section of pipe is then raised to a welding heat and slipped over the smaller section for about 18 inches (fig. 928) The two are then passed through special rolls which draw the end of the larger pipe down like a bottle neck, and the tube in cooling takes a firm grip on the smaller section of pipe

If lap-welded pipe is used, care should be taken not to have two of the lap-joints in the different sections of pipe coincide The tubes are sometimes riveted as well as lap-welded, and the dimensions of these poles will vary somewhat with different makers and the different strains they are called upon to bear Table A shows some of the usual sizes of poles and the thickness and weight of metal

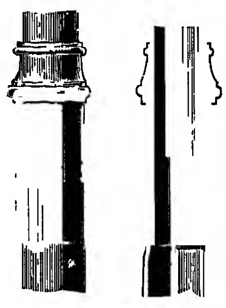


Fig 928 —Section and Elevation of Pole Joint

Taper Poles.—A second type of pole is met with, having a taper either for the whole or part of its length These are usually drawn parallel for 15 or 17 feet of their length, and from thence tapering to the end The taper is obtained by passing them through eccentric rolls These taper poles are sometimes made in one piece and sometimes in two, the lower or parallel section being shrunk over the upper or taper section

Although these poles have been used on a number of tramways, there appears to be no special advantage in them other than their appearance, which is in some cases preferred to that of the three-jointed pole The taper pole does not lend itself to ornamentation as well as the parallel-sided pole, and is somewhat more expensive.

Solid-Drawn Poles—The third variety of pole is solid-drawn in one piece, and of three different diameters, the sides being parallel The appearance of these poles is practically the same as the jointed poles The varying diameter of pole with the shoulder is obtained by reversing each set of rolls at exactly the right point Poles drawn by this method should have advantages over both of the other types, but in practice they are not found absolutely reliable in strength, owing to the difficulty of reversing the rolls at the desired point. If this is not done the metal is stretched at the shoulder, leaving a weak spot in the pole.

The poles are usually designated by the number of pounds strain they will bear with a given deflection, usually 6 inches, it being assumed that the pole is held securely for the first 6 feet of its length, and the strain is

either applied at the top, or, what is more convenient, at the point where a strain will come in practice, usually about 22 feet from the ground-line. The temporary deflection of 6 inches has come into general use, as a pole may be curved to this extent after erection and yet appear straight to any but a trained eye.

TABLE A

Three-Section Lap-Welded Steel Poles

Tensile strength about 24 tons per square inch

Top Section, 7 feet 6 inches		Middle Section, 9 feet 6 inches		Bottom Section, 17 feet		Total, 31 feet	Strain in lbs to produce	
Inside Diameter, inches	Thickness, inches	Inside Diameter, inches	Thickness, inches.	Inside Diameter, inches	Thickness, inches	Weight of Pole	6 inches Temporary Deflection	½ inch Permanent Set
4	.23	5	29	6	42	720	350	700
5	26	6	31	7	40	836	500	1000
5	30	6	38	7	47	990	700	1200
6	30	7	40	8	60	1321	1000	1700
7	30	8	40	9¾	65	1593	2000	2600

Tensile strength 28 tons

9 feet		8 feet		17 feet				
Outside		Outside		Outside				
5½	259	6⅝	30	7¼	40	830	900	
6⅝	30	7¾	40	9	50	1210	1200	

Three-Section Solid-Drawn Steel Poles

Tensile strength 35 tons per square inch

7 feet 6 inches		9 feet 6 inches		17 feet				
Outside		Outside		Outside				
4½	30	5 9/16	30	6⅝	375	720	500	1000
5 9/16	30	6⅝	30	7⅝	3125	800	700	1200
6⅝	30	7⅝	30	8⅝	.3125	890	1000	1700
7⅝	3125	8⅝	.3125	10	375	1140	2000	2600

Poles in One Length Stepped

Tensile strength 35 tons per square inch

6 feet		6 feet		19 feet				
Outside		Outside		Outside				
4	.3125	6	3125	7¾	3125	680	700	1200
5	3125	7	3125	8¾	3125	796	1000	1700
7	3125	8½	3125	10¼	3125	922	2000	2600

Lap-welded taper poles in one piece; the bottom half their length parallel, the top half tapering.

Outside		Outside				
7 inches tapering to	5 inches;	thickness,	⅜ inch	780	700	..
8 " "	6 "	"	7/16 "	1025	1000	
9 " "	7 "	"	½ "	1300	1200	
7 " "	4 "	"	⅜ "	740	700	
8 " "	5 "	"	7/16 "	1050	1000	..

Poles are generally specified to be perfectly straight and to show no permanent deflection at the designate strength. An additional test is sometimes specified, that the poles shall not show more than $\frac{1}{2}$ inch permanent deflection after being subjected to a strain about 50 per cent greater than the designate strength. The diameters of the various sections should not vary more than $\frac{1}{16}$ inch from the standard dimensions, and the tubes should be as nearly cylindrical as possible. The difference between the maximum and minimum diameters should not exceed $\frac{1}{8}$ inch The necessity for these limits of variation is that the cast-iron pole trimmings shall fit easily

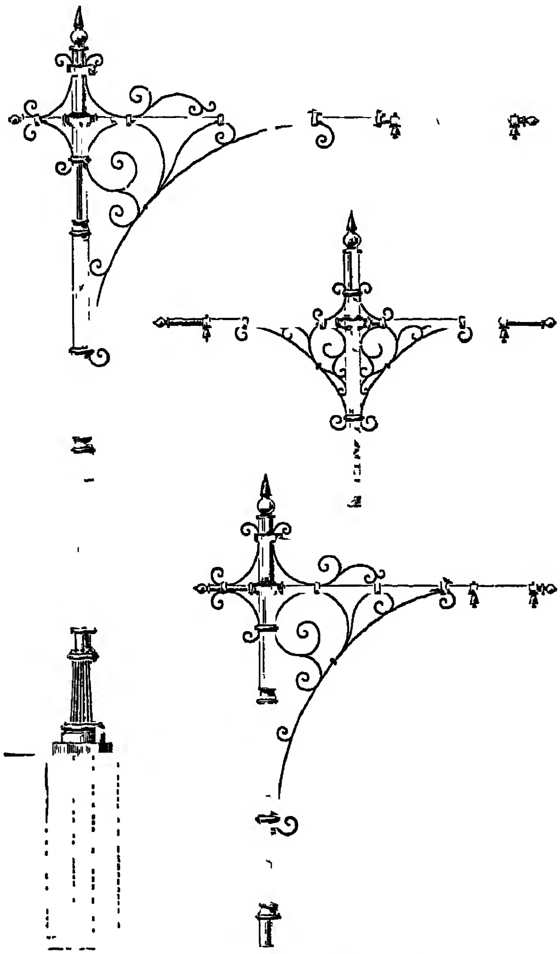


Fig 929 —Various Forms of Bracket Design

Where poles are made in more than one piece a drop test is also requisite The usual test is to drop the pole, butt foremost, from a height of 6 feet on to some solid substance, such as a block of iron or stone, some engineers going even so far as to repeat this test three times It will be seen on a little consideration that this test is much more severe than the conditions under which the pole is to be used would render necessary, there being comparatively little downward pressure on the pole when in use.

If the poles are to be set with a derrick, as is the almost universal practice, a drop test of one-half the amount would suffice, but if the poles are to be raised by hand and dropped into the holes, the 6-feet test becomes a necessity

Care should be taken to protect the poles from rust inside and beneath the ground-line. One method of accomplishing this is to dip them about 7 feet into a suitable rust-preventing compound. Another is to dip the entire pole in a bath of oxide paint, thus coating it inside and out It might even be advisable to adopt both methods.

Pole Trimmings and Brackets.—The design and dimensions of these will be largely governed by individual taste and the money available for purposes of ornamentation.

The pole trimmings usually consist of a finial slipped into the top of the pole, two pole rings or collars slipped over the joints or shoulders in a parallel-sided pole, and a base of such height and design as may be desired. In some cases small, low, plain bases are used in the outlying portions of the system, and in others the high bases are used throughout

In selecting designs for these pole bases it should be borne in mind that the base of large diameter is frequently a great obstruction to foot-passengers, particularly when the footpaths are narrow, as is often the case in some of the older cities. Also a base with a great deal of ornamentation upon it becomes splashed with mud from passing vehicles, and is very difficult to keep clean, and when the ornamental work is full of dry mud the general effect is not as pleasing as a plainer base would be

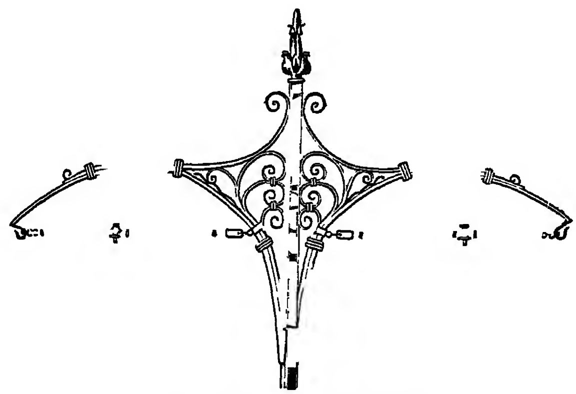


Fig 930 —Double Bow-String Bracket

Brackets are of two general varieties — one consisting of a piece of tubing of suitable diameter, usually $2\frac{1}{2}$ to 3 inches, and of a required length This tubing is supported to some extent by the scroll-work underneath, but chiefly by a tension-rod running to the top of the pole (fig. 929)

The second type (fig 930) is what is usually known as the bow-string bracket This is not mechanically a good design, but has met with a very considerable amount of favour, particularly for centre-pole work, as the absence of straight lines is supposed to give a pleasing effect to the pole

The bow-string bracket is made up entirely of wrought-iron of suitable sections, which must, however, be much heavier than in the first type of bracket In both cases heavy cast-iron collars made in two pieces are held together by two or four bolts (fig. 931) The inside of these collars should fit the circumference of the pole as closely as possible, and to these collars are attached the bracket arms proper or the scroll-work Similar collars, but smaller, are also used to secure the scroll-work to the bracket arm in the case of a pipe bracket. All these cast-iron collars, upon which the strength of the bracket depends, are made of malleable cast-iron. The scroll-work is made to suit the taste of the designer. The various portions of the scroll-work are held together—in some cases by welding, and in others by having small iron collars cast about them. If expense is to be avoided, the design should be such as may be made with the fewest number

of welds. Circles should also be avoided, as they are difficult to make, and thus add considerably to the cost

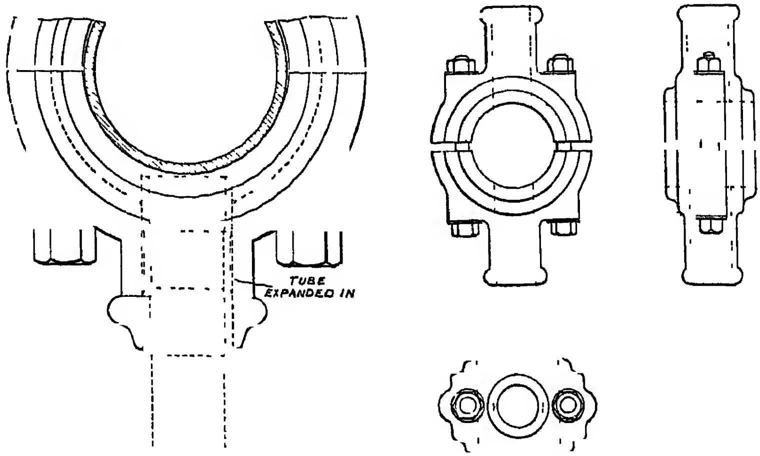


Fig 931 —Split Collars for securing Brackets to Pole with Bolts

The best effects are obtained from the brackets which are not too elaborate, for it must be borne in mind that the design which is most pleasing on the drawing-board is often disappointing when erected.

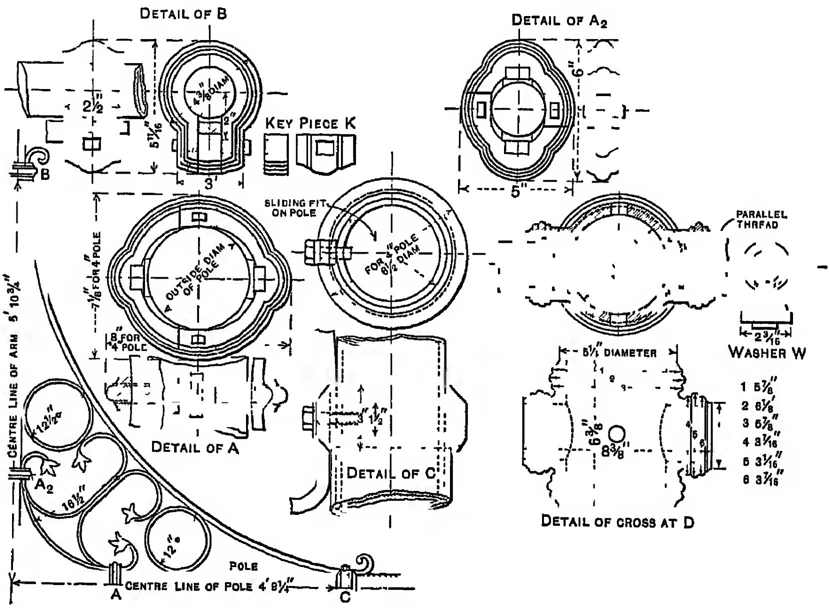


Fig 932 —Details of method of securing Bracket to Pole with Collars

Owing to its height from the ground much of the detail is lost, and the bolder, more simple designs are most effective. Another mistake that is frequently made in bracket design is the use of metal of too light a

section, $\frac{3}{8}$ or $\frac{1}{2}$ inch by $1\frac{1}{4}$ inch being employed The effect of this thin section is to obscure the detail, as when it is against the sky it is almost invisible. Also, unless looked at from exactly the right point, the curves of the two edges do not coincide, and this causes them to appear untrue It is much better to make the scroll-work of metal having a section nearly square, even if no more metal is used, in fact, the circular section might be used in some cases to advantage.

Another method of securing the various portions of the bracket together, and to the pole, has been designed by the writer for Coventry (fig. 932), using collars instead of bolts This is shown in detail, but in practice does not possess any advantage over the usual method, beyond having the collars look slightly neater

Where span-wires are used, it has now become customary to place on the top of the pole a small scroll-work bracket, which has the effect of subduing the extremely severe lines of the pole (fig 933). These span-wire brackets usually extend 18 inches from the pole on each side, and the span wire is attached to one end of the bracket arm There is no advantage in using this except its improved appearance

As before stated, the flexible type of bracket suspension is essential to smooth running This in effect is the conversion of the overhead system into span-wire work as far as the support of the actual wires and insulators are concerned With the bow-string type of bracket it is accomplished by attaching a small length of steel cable to each end of the bow, forming, in fact, the bow-string (fig 930), which is always provided at one, and sometimes at both

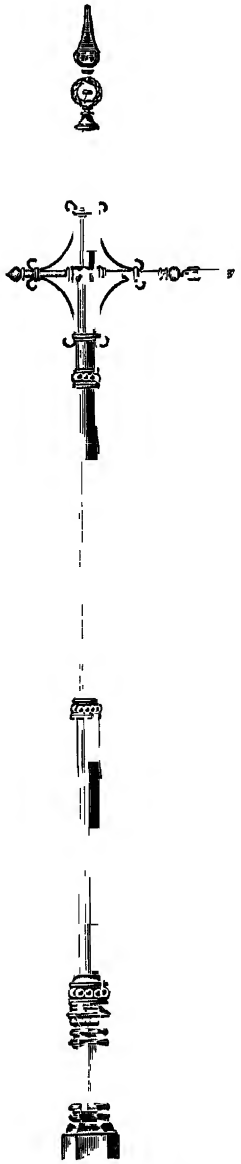


Fig 933.—Side Pole and Span-Wire Bracket

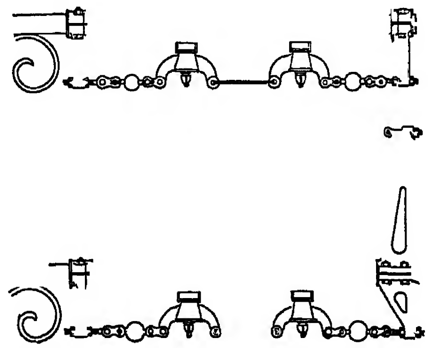


Fig 934 —Flexible Bracket Suspension with and without Guard-Wire Support

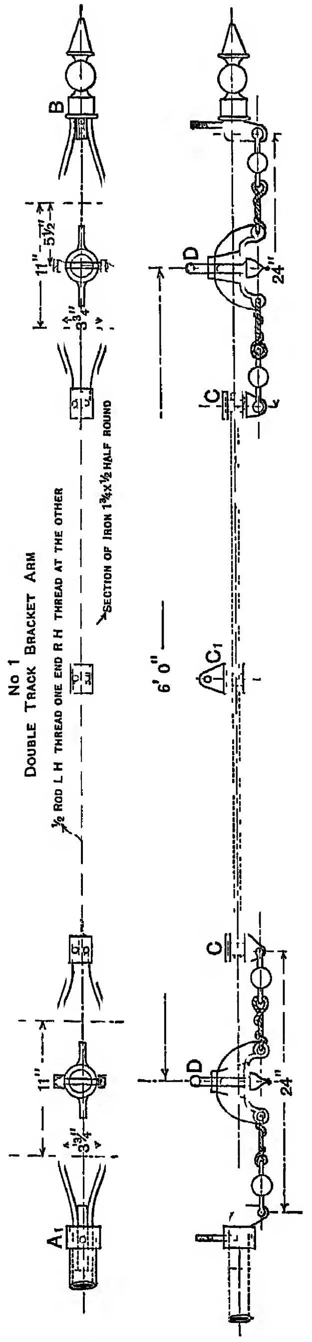
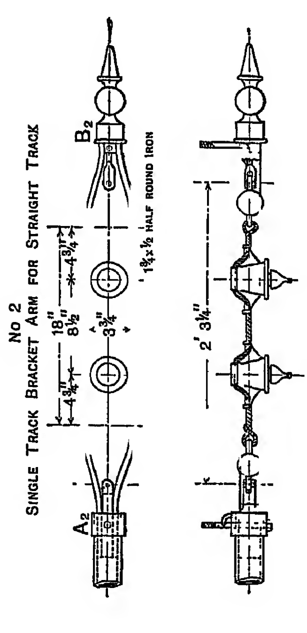


Fig 935 —Horizontal Harp-type of flexible Bracket Suspension



ends with a suitable screw-bolt for putting the requisite tension on the cable

In the case of the straight bracket arm it is usual to clamp to the pipe forming the bracket two lugs of suitable depth and design (fig. 934) These are placed at a convenient distance apart according to the length of the bracket, usually from 2 feet 6 inches to 3 feet 6 inches, and the lower end of these lugs is provided with a screw for putting the tension on the cable The top of the clamp holding these lugs is sometimes extended 1 foot to 18 inches upwards, in order to carry the guard-wires where required

Another form of flexible suspension was designed by the writer for Norwich, which consists of forming a harp on the end of the bracket arm (fig 935) The harp lies in a horizontal plane and has the steel cable in the centre This has a very neat appearance and considerable strength in a vertical direction, but is weak longitudinally

At a little distance this cannot be told from the rigid type of suspension, and has generally a lighter aspect than the ordinary type It, however, has the drawback of requiring exceedingly careful adjustment of the trolley wire longitudinally, otherwise the bell of the insulator is liable to touch the side of the harp and destroy the secondary insulation This can be overcome to some extent by using an insulating bell having the span wire attached at the top instead of about the middle.

A flexible suspension, consisting of two short chains fastened to the

bracket arm 6 or 7 inches apart, and supporting the insulating bell, has also been used, but it is apt to be noisy in practice, and in certain places, where there is little or no downward pressure on the trolley wire, is liable to have the secondary insulation broken down by the trolley wheel pushing the bell up against the arm.

Steel Cable—The use of a stranded steel cable for supporting the trolley wire and insulators has now become universal, the solid steel wire having been abandoned

A steel cable is usually of seven strands and galvanized. The minimum size which should be used is 7/14, and it will, of course, be necessary to increase this size at points where there is an extra heavy strain The breaking strain of the smallest size should not be less than 2500 lbs

In calculating the size of cable required a liberal factor of safety should be allowed, usually 5 to 6

The galvanizing should be of the best quality, and the wire should be capable of being wrapt around its own diameter and unwrapt without the galvanizing showing signs of cracking In addition to the galvanizing, special means should be taken to protect the wire from the corrosive action of smoke, chemical fumes, or rust It is nearly always considered sufficient to pass the end of the cable through the eye of the strain insulator or hanger, and then either nozzle off the wire or make a Britannia joint. But owing to the vibration of the entire overhead system and the tendency of water to collect at this joint, it cannot be depended upon for more than about five years Therefore at every point where steel cable is attached to an insulator or hanger, it should be passed around a galvanized or brass heart-shaped thimble and spliced or nozzled off The Britannia joint is not advisable, as it has a tendency to soften the wire, and as it is difficult to make this joint without an acid flux, it is better to avoid the joint altogether.

In a bracket system it is good practice to make all the spans for the flexible suspension in the shop, of standard lengths, and then saturate them thoroughly with P. & B. or other waterproof compound

In spans extending across the street, or for pull-offs or anchors, this method is not practicable, but after the joint is made around the thimble it should then be saturated with the same compound, and at such time during the carrying out of the work as is convenient be painted throughout its entire length These precautions are particularly necessary in span-wire work and with long pull-offs and anchors, as if one of these wires fail it usually is of sufficient length to curl around the trolley wire and fall into the street, which may cause a serious accident

Trolley Wire.—This is now practically always made of hard-drawn copper wire, although silicon-bronze and phosphor-bronze have been used to some small extent Although these latter have a much higher tensile strength than the hard-drawn copper wire, their conductivity is much less, about 60 per cent, and they are also much more troublesome to handle, so that their use has not become very general.

The following are the sizes and particulars of the trolley wires in most common use:—

TABLE B

Standard Gauge	Diameters in inches	Sectional Area in sq inches	Weights in lbs		Resistances per 1000 feet in International Ohms	
			1000 feet	Mile	At 60° F	At 75° F
0 000	400	1257	484	2 557	06363	06567
000	372	1087	419	2 212	07357	07593
00	348	.0951	367	1 935	08407	08676
0	324	0824	318	1 678	9698	10009

The No 000 seems to be the one generally specified The larger size necessitates a considerable increase in the strength of the pole, span-wires, and insulators

The trolley wire should have an electric conductivity of at least 98 per cent Matthiessen's standard, and should be perfectly cylindrical in section, and free from scratches, flaws, and other defects

Considerable attention should be paid to the joints in the trolley wire, and they should be either electrically welded or else a long scarf and brazed joint made The scarf should be at least 1 foot 6 inches in length, and preferably longer, and in any case the joints should be made before passing the wire through the draw-plate which reduces it to its final size.

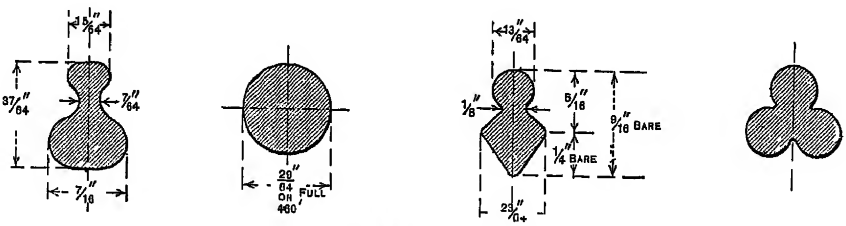


Fig 936 —Sections of Trolley Wire

Trolley wire can now be obtained in any reasonable length It is, however, usually put up in mile or half-mile reels The former is preferable, and it is also an advantage to have the reels run somewhat over a mile, 2 or 3 per cent The requirements of the Board of Trade demand that the trolley wire shall be divided into half-mile sections, and it is not always possible to get these exact, they frequently run a bit short or a bit over, and there must be a certain amount of allowance made for dip in the spans, and it is easier to run out two sections together than to have to mount a fresh reel for each section

It is not good practice to allow joints in the work, either by means of a splicing sleeve or a splicing ear, although both are often used It is difficult to get these joints made in the street to run without sparking, and consequently in time the trolley wire is liable to be weakened at these points

There have been a number of different sections of trolley wire tried,

such as "figure 8", "notched", and "trefoiled" (fig. 936), the idea of these being to allow the use of mechanical ears and still have a smooth running surface for the trolley wheel Owing to the great difficulty in preventing these wires from twisting between the points of support they have not been much used.

Trolley wire should be delivered upon drums having as large a diameter as possible, not less than 3 feet, and 4 feet is preferable. It should be reeled perfectly true and even, and free from kinks and sharp bends.

Ears—These are of two general varieties, the mechanical ear and the sweated-on ear.

The mechanical ear is one which is made to wholly or partially enclose

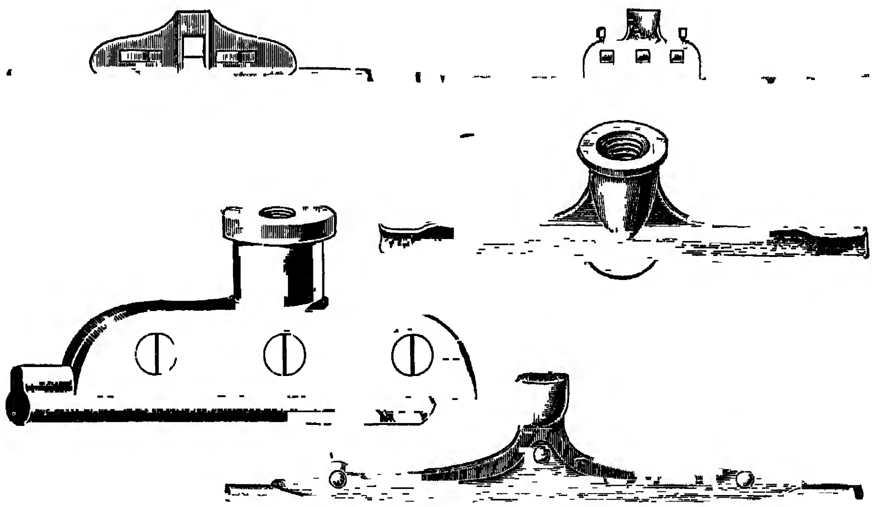


Fig 937—Various Types of Mechanical Ears

the trolley wire, and holds it by friction There have been a very large number of these designed and patented, and a few of the principal types are shown (fig 937) They are very much easier to put up than the soldered-on ear, and considerably reduce the cost of labour in building a trolley line, but as yet none of them have been so designed that they will run without sparking In order to get sufficient strength to grip the trolley wire they are usually made heavy and rigid, and the consequence is that in time the trolley wire is likely to break off at the ear from continual flexure They are useful, however, for emergency repairs, and they may also be used to advantage in complicated junctions to hold the wire in place temporarily until the exact position of the ears can be determined

The sweated-on ear is made in several designs and lengths, but the difference is chiefly in detail. The most usual lengths are 15, 18, 24, and 36 inches In some cases the ears encircle about 180° of the section of the trolley wire.

Another pattern is provided at each end with wings about $\frac{3}{4}$ inch

long that nearly encircle the trolley wire (fig. 938). A still better form of ear for heavy work is one that encircles about 240° of the trolley wire throughout its entire length. These are known as deep-groove ears, and are frequently ribbed.

All ears should be drawn down fine at the ends, as it renders them more flexible, and allows them to take up a slight curve in either the vertical or the horizontal plane, thus avoiding the sharp angle produced by the mechanical or rigid ear It in fact forms a parabolic curve, which the trolley wheel takes with a maximum of ease.

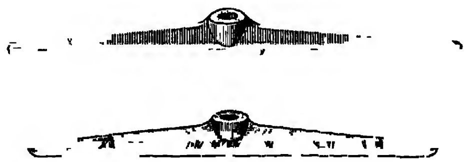


Fig 938 —Winged and Deep-Groove Ears

The ears should always be delivered thoroughly tinned on the inside. 15-inch ears without wings, and a shallow groove, may be used on straight lines with No 0 trolley wire; but 18-inch ears with small wings should be used at the curves, and it is much better to use ears with wings exclusively.

For the larger size of trolley wire the deep-groove ear is more suitable, and may be with advantage increased to 18 inches in length on the straight and 24 inches on the curves 36-inch ears are needed in comparatively rare instances, although on some tramways they have been used on all curves.

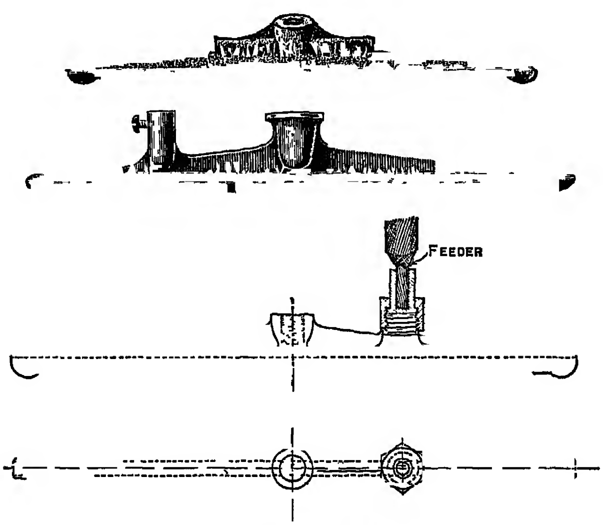


Fig 939 —Types of Feeder Ears

This tendency to increase the length of the ears beyond 24 inches is wholly unnecessary, as the gain in smoothness and certainty of running is not commensurate with the extra cost entailed by the very heavy insulators and span wires required This to a certain extent means the strengthening of all the overhead work to correspond.

This principle of easing the curves by ears of great length was considered essential about twelve or fifteen years ago, but was shortly after abandoned. The method at that time was to use from three to six ears of ordinary length, the ears being bolted to a steel plate about $\frac{3}{16}$ inch thick by $1\frac{1}{2}$ inch in width. This made the length of attachment on the trolley wire from 3 to 6 feet.

The span-wire was attached to the usual form of yoke, to the centre of which was secured the steel plate. This, of course, made a very sweet curve which the trolley wheel followed very easily, but with the improvement in the trolley standards these were found to be unnecessary

Feeder Ears.—A certain number of ears designed to allow the trolley wire to be fed at desired points will be required. Several types of these are shown (fig. 939). A feeder ear should be so designed as to have ample contact area between the ear and feed-wire, which contact should be perfectly secure and easily detachable.

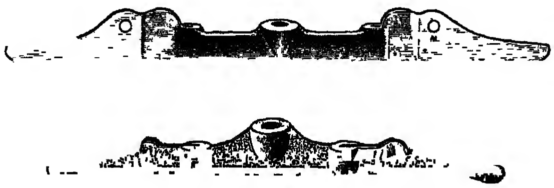
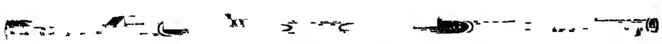


Fig 940 —Two Types of Splicing Ears

Splicing Ears.—Splicing ears are usually made as shown (fig. 940), although there are numerous other designs having slight differences It is of great importance that the fine end of the ear should be carried out to a good length, and the ear should have considerable depth, and be as thin as the required strength will allow It is somewhat difficult to get these splicing ears to run smoothly, as, owing to their great weight, they form a more or less rigid spot in the line, which is apt to make the trolley wheel spark It is better practice to avoid the use of these as far as possible, as this can be frequently done without excessive waste of trolley wire by the exercise of a little care in arranging the lengths of the sections and in the selection of reels



Philadelphia Sleeve

Trolley-Wire Splicing Sleeve

Fig 941

of wire of proper length. Splicing sleeves are sometimes used (fig. 941), but they are not recommended except for emergency work.

Hangers and Insulators.—The use of hangers is to afford support for the insulation, and to afford a means of attaching the insulator to the span-wire or brackets. The requirements of a hanger are that—

(1) It should be of a design giving ample mechanical strength without excessive weight.

(2) It should as far as possible protect the insulating material from the weather.

(3) It should support the insulator in such a way that the strain is distributed over as great an area of insulating material as possible.

(4) It should be so designed that a single form of insulator can be used under all circumstances

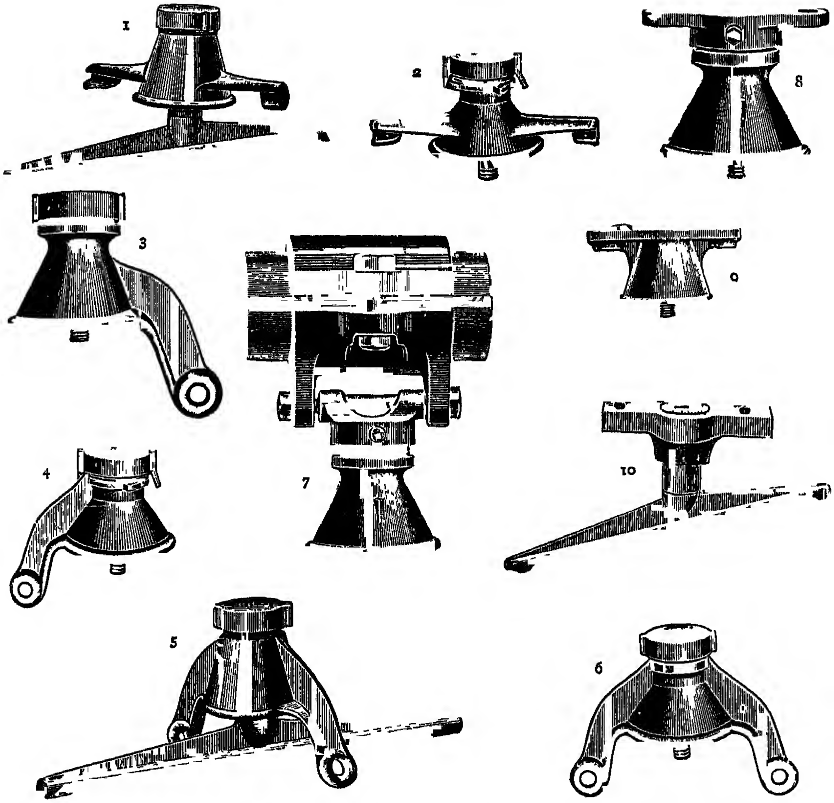


Fig 942 — 1, 2, Straight Line 3, 4, Single Pull-off 5, 6, Double Pull off 7, Bracket Hanger 8, 9, 10, Bridge and Car Barn Hangers

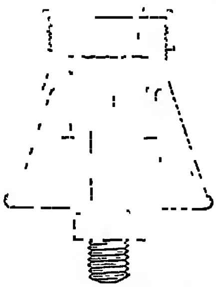


Fig 943 —Section of West-End Hanger

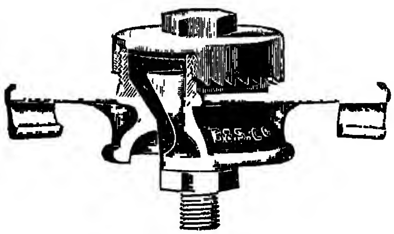


Fig 944 —Straight-Line Hanger

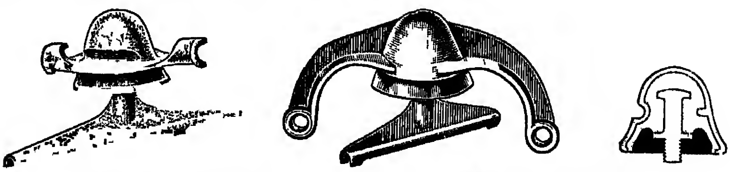


Fig 945 —Solid Bell Type Straight Line, Double Pull-off, and Section

(5) It should prevent the trolley wire from falling into the street even if the insulating material is entirely destroyed

(6) It should allow of an ample extent of insulating material between hanger and ear for the prevention of surface leakage.

(7) It should be made of material as non-corrosive as possible.

This last feature can best be obtained by the use of bronze, which is considered essential in all first-class work Malleable iron galvanized or painted is used to some extent where first cost is of great importance, but the maintenance is much higher

The type of hanger that most nearly combines the above requirements is what is commonly known as the "West-End" type, varieties of which are shown (fig 942).

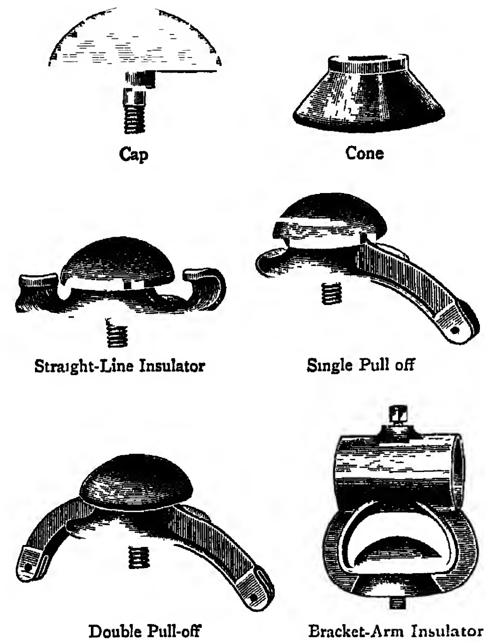


Fig 946

The main defect of the West-End type is that the strain on the hanger has a tendency to bend the insulating bolt and concentrate a considerable strain at the point A (fig 943) And in order to get sufficient strength to resist this bending tendency, the bolt is made of steel

The insulating material commonly used has considerable strength but very little elasticity, and a comparatively slight flexure of the bolt will cause the insulating material to crack This does not affect the insulation at first, but moisture gradually soaks in and the steel rusts, and splits off the insulation from the outside. This can be guarded against to a great extent by carefully painting with P. & B. compound that portion of the insulating bolt projecting from its supporting sleeve.

A modification of the West-End type possessing considerable merit is shown in fig 944

Another design of hanger known as the Solid Bell (fig. 945) is also shown. In this the insulating material is forced into a cup-shaped casting, and the bolt for holding the ear is embedded in the insulating medium. This design is very difficult to erect, as it is necessary to attach the insulator to the trolley wire before attaching it to the span-wire or bracket, which makes repairing very difficult. It also has the disadvantage that if the insulating material fails it allows the trolley wire to fall.

A third design, used to some extent with what is known as the cap-and-cone insulator, is also shown (fig 946). This is a very good design, and is entitled to more consideration than it has generally received. It

fulfils all the requirements stated above, with the exception of the protection of the insulating material from the weather, in which respect it is inferior to the previous types described, but if the cap is made of vulcanite or kept well painted, it is a very satisfactory form of insulation, and is to a large extent free from the defect of the West-End type.

Several types of rigid bracket hangers are shown (figs 942 and 946) Secondary insulation is obtained by the use of a sleeve of insulating material slipped over the bracket arm. This rigid type may be used for slow speeds, but is not to be recommended.

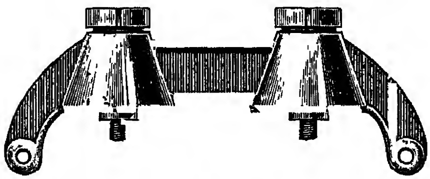


Fig 947 —Double West-End Hanger

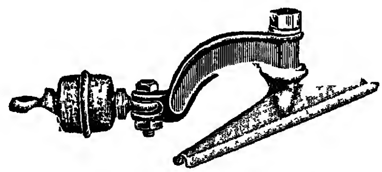


Fig 948 —Single Giant Pull over

It is now usual practice to run two trolley wires over the entire system—on single track as well as double Where this is done on single track, the two hangers are sometimes cast in one piece as is shown (fig 947), but this brings the trolley wires rather closer together than is usually advisable, and if the distance were increased the weight of the fitting would be too heavy for general use

Another type of hanger is shown (fig 948), which consists of a heavy yoke with a globe insulator at each end, and the ear bolted to the centre

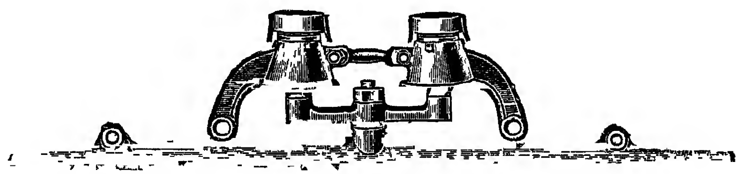


Fig 949 —Double West-End Pull-off for Points of extra Strain

of the yoke. This type has some advantages for certain classes of work It is not as neat in appearance as the West-End type, but has much greater strength, and can be used with advantage under conditions where the strains are too great for the West-End bolt, and if a suitable type of globe strain insulator is used and care taken to keep the insulators well painted it will give most satisfactory results

Another method of dealing with points of exceptional strain is shown (fig 949). In this two West-End bolts and hangers are used in such a way that the strain is distributed between the two

Strain and Globe Insulators.—These are used chiefly for secondary insulation, at the terminals of a line and for pulling frogs and crossings into position. The strain insulators are always provided with some

arrangement for putting tension on the wire to which they are attached. They are of several types. The most usual are the Brooklyn, either single or double according to circumstances, and the King insulated turnbuckle (fig 950).

The Brooklyn is a very efficient form of tension device, and is usually made entirely of bronze, and is to be recommended for span-wires or anchorages on first-class work The King turnbuckle is an efficient insulator with a considerable range of adjustment, and is very useful in span-wire work, but being made entirely of iron it is apt to rust, and cannot be adjusted after it has been in place for some time

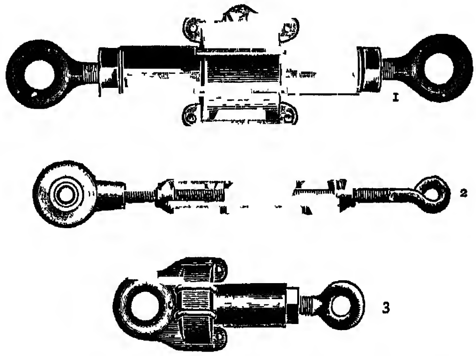


Fig 950 —1 and 3, Brooklyn Strain Insulators, 2, King Insulated Turnbuckle

Globe Insulators.—The globe insulator is made as shown (fig 951). It is composed of two eye-bolts with a peculiar-shaped ring and hook on their respective ends These are interlocked and embedded in a globe of insulated material They are made in several sizes, and designed for several different types of attachment

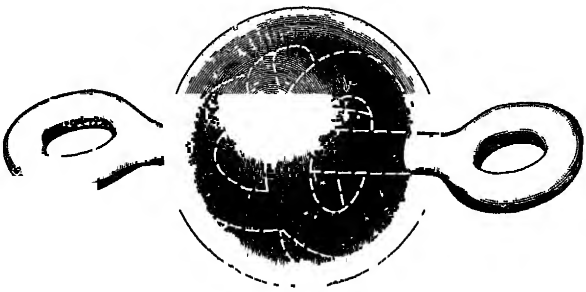


Fig 951 —Globe Strain Insulator, showing Internal Links

Another type of globe insulator is also shown (fig 952) In this case it will be noticed that the insulating material is in compression between flat surfaces In this type the portion of insulation in compression is sometimes made of the usual plastic moulded composition, and in others of sheets of cut mica, and the whole arrangement is afterwards moulded into insulating material, usually in elliptical form.

Another type, which also has its insulating material between flat surfaces, is shown (fig 953) The result is arrived at in a slightly different way, and being made up entirely of drop forgings, should have greater mechanical strength for a given weight, but does not appear to be quite so good electrically as the cut mica This second type is much preferable to the first, and is much more durable.

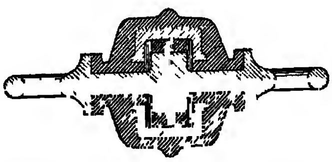


Fig 952 —Section of Giant Strain Insulator

Bridge hangers and car barn hangers are shown (fig. 942), and their uses and advantages dealt with later on.

Section Insulators.—Under the Board of Trade regulations, and also for convenience in working, it is customary to divide the trolley wire up into sections of approximately one-half mile in length, and in order to accomplish this a section insulator must be used, which will preserve the mechanical continuity of the line and running surface for the trolley, and at the same time insulate the respective sections from each other. A number of designs for accomplishing this are shown.

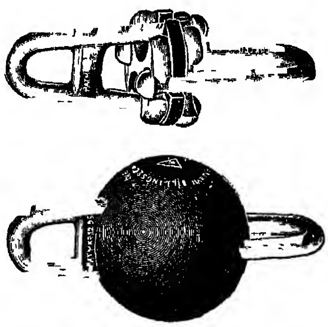


Fig. 953.—Globe Strain Indicator, and details.

There are two methods used for preventing the current from following the trolley wheel from one section to another, and thus forming an arc—the long-break (fig. 954) and the divided-arc system (fig. 955). The former is in the most general use, and is accomplished by the insertion in the section insulator of an insulating strip 8 or 10 inches long, upon which the trolley wheel runs. The strip is usually made of hard wood or fibre, and as it wears in time with the passage of the trolley wheel and with sparking it is designed to be readily renewable.

In the divided-arc principle a number of small metallic sections are bolted together, insulated from each other at the top end, and separated at the bottom by an air-gap, usually from $\frac{1}{8}$ to $\frac{1}{4}$ inch in extent. And the arc which tends to follow the trolley wire is divided up into these small gaps, and goes out without trouble.

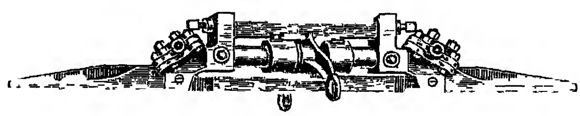


Fig. 954.—Section Insulator, Gate Type. Long-Break.

These are more expensive, and do not seem to present any particular advantages over the other types.

There is no great difficulty in training the motormen to shut the current off and coast under these section insulators, in which case the renewal of the insulating strip is very infrequent, and in any event is inexpensive. Another type designed to avoid the necessity of shutting off

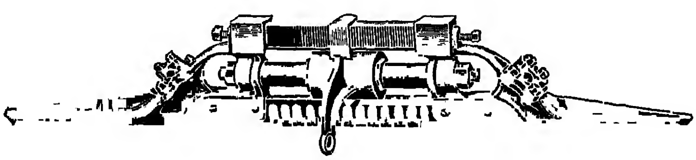


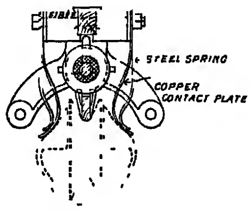
Fig. 955.—Section Insulator, Divided-Arc Type.

the current when passing under is shown (fig. 956). This type will be found useful on gradients.

The most usual form of the section insulator is what is generally known as the gate type (figs. 954, 955, and 956), in which the centre member is in tension and the top member in compression. This latter member is

sometimes made adjustable in length by means of set-screws at the ends. The bottom member of the gate is the renewable wearing piece above referred to, and does not take any of the strain. This type of insulator is one of the straight under-running varieties, which may be worked at higher speed than those of the fish-belly type. The latter can, however, be made less cumbersome in appearance, as the strain on it is a straight pull.

Section insulators should always be so placed that the strain on them is a straight pull, as they have little or no lateral stiffness, and if they are used as pull-overs they are sure to give trouble



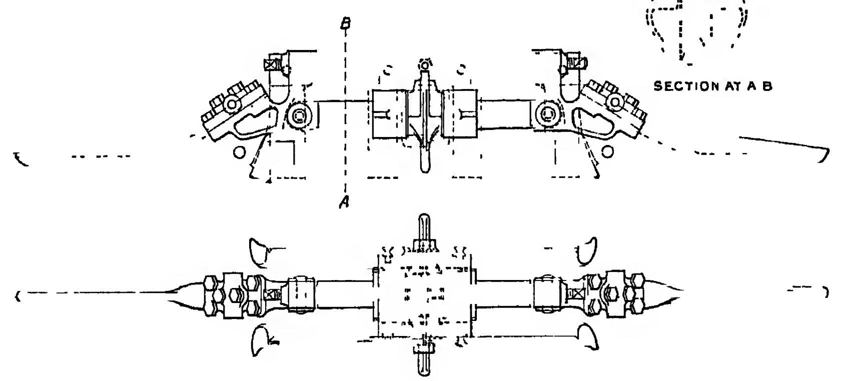


Fig 956 —Continuous feeding Section Insulator

Hewer's section insulator (fig 957), which has recently been brought out, is of the fish-belly type, and so designed that the strain is taken by two bolts placed some inches apart in the same horizontal plane as the trolley wire This type has considerable lateral stiffness, and by making the ears long and fine, might be used on a decided curve without difficulty

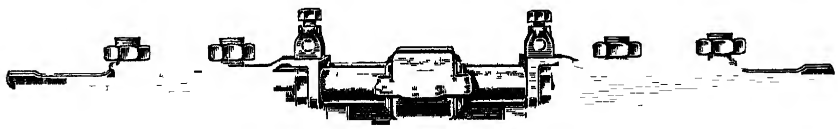


Fig 957 —Hewer's Section Insulator

Section insulators are usually furnished with terminals at each end, so that they can be used as feeding-in points. These terminals are also useful if it is desired to put on a jumper to connect the trolley wires to each other Two general types of terminals are used—one a socket with one or more set-screws, and the other holding the wire in a clamp, the cap of which is held in place by a number of bolts. In the first type the set-screws are apt to work out from the vibration of the trolley wire, and make a loose contact that will arc and heat, or else release the feed-wire.

The clamp is much more secure, but is very troublesome to disconnect in a hurry, as is often necessary when working,

A modification of the gate type of section insulator is shown (fig. 958), which was designed by the writer for Reading to overcome these faults in regard to the terminals. This is provided also with spring contacts for the insertion of a jumper without disconnecting the feeding-in wires The ears have also been lengthened to make a quieter running insulator.

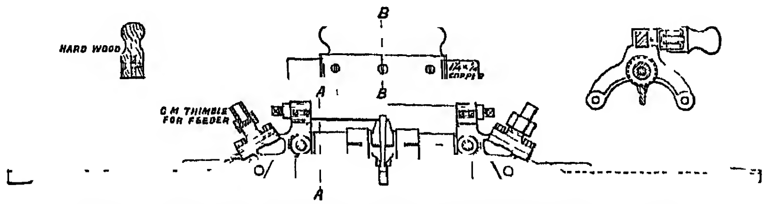


Fig 958 —Section Insulator with Short Circuiting Switch and "Union" Terminals

Section insulators are frequently supported by being rigidly attached to bracket arms. This is distinctly inadvisable, as when so erected the trolley makes a great deal of noise in running over them, and the shock in passing from the flexible line to the rigid insulator will sometimes make the trolley wheel leave the wire Owing to the extra weight of the section insulator, particular care should be taken to have its suspension flexible, and the ears holding the trolley wire long and thin, to compensate for the extra weight of the insulator

MISCELLANEOUS FITTINGS

Bell Insulator.—A useful type of bell insulator is shown (fig 959) They can be fitted with any desired form of terminal at either top or bottom, and are sometimes useful when it is desired to keep two adjacent wires from coming in contact by swinging together

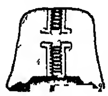


Fig 959 —Section of Bell Insulator

Terminal Clamp.—It is advisable at the end of a trolley line to secure the wire in some form of a clamp as shown (fig 960). If the strain is not great a simple eye can be bent up in the end of the trolley wire, but the copper eye being of soft metal is liable to wear through in time.

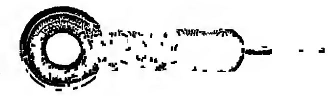


Fig 960 —Terminal Clamp

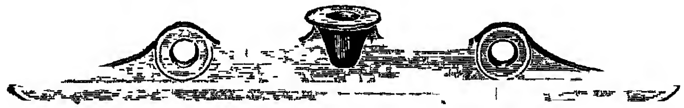


Fig 961 —Anchor or Strain Ear

Anchor Hangers.—In most cases it is preferable to attach the anchorage wires to the hanger instead of to the ear (fig 961), for an anchorage attached to the ear is very apt to foul the trolley wheel, and also has a tendency to kink the trolley wire If a very heavy strain on the anchorage

is unavoidable, it is best to use a type which distributes the strain between two bolts as shown (fig. 962)

In some cases it may be useful to provide the trolley wire with a protecting sleeve 3 or 4 feet long. This is slipped over the trolley wire close to the section insulator or frog, or other point where especially heavy wear is expected.

Rosettes.—Where it is possible to obtain permission to attach rosettes to the faces of the buildings along routes, it is of considerable advantage to do so, and even if this cannot be done to a large degree, there where they can be used for pull-offs or special purposes and pole, even if it is not desirable to erect any length of line by sus-pension.

Several types of rosettes are shown (figs 926 and 927). These should be provided with from two to four bolts for letting into the wall. If the walls

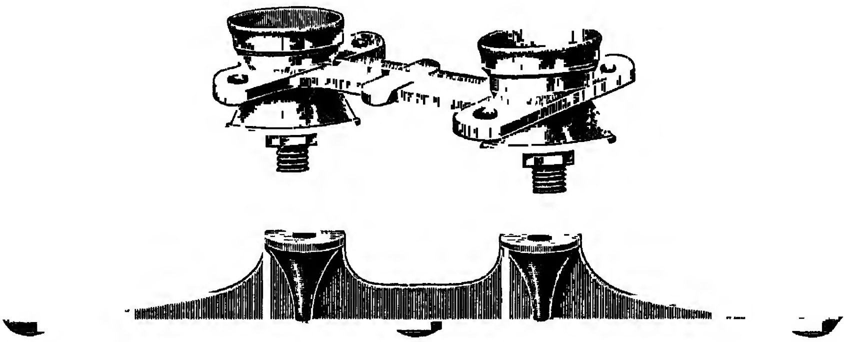


Fig 962 —Double Anchor or Strain Ear

are sound, the smaller type with the holes close together can be used, but if the strain is very heavy or the wall is weak, it is preferable to use rosettes with a large back-plate so as to distribute the strain over a larger portion of the wall.

The rosette should be designed to allow a certain amount of adjustment to permit the span-wire to take up its proper direction, and all rosettes should be provided with a rubber buffer to act as a sound damper to absorb the vibrations from the span or pull-off wires

Frogs and Crossings.—Frogs may be divided into two general classes those designed for working with a fixed trolley head only, and those specially designed for use with a swivel trolley head.

The rigid trolley head will work with any type of frog, provided the frog is set in the correct position, but it is generally used with what is known as the fixed frog, which is shown, fig. 963. These frogs are rigid castings, and it depends entirely upon their position which wire the trolley wheel will follow, the principle being to place them so that when the car takes the branch track it will drag the trolley wheel along the side of the casting and cause it to follow the proper wire.

These frogs are classified as right, left, equilateral, and three-way. The last-named is only used in very special circumstances, and is not to be

recommended, as it will not work with anything approaching certainty except when worked as a trailing frog The other frogs will work with practical certainty as trailing frogs, and a very considerable degree of certainty facing, if kept correctly set.

Crossings are of two general types as shown—the fixed (fig. 964) and the adjustable (fig 965) crossings The adjustable is preferable, except perhaps for right-angle crossings and extremely sharp angles The principle upon which these work is easily seen from the illustrations.

Crossings should preferably be placed so that neither of the wires change their direction when passing through the crossing, but with a fixed head they will work with a fair degree of satisfaction with a considerable angle in one or both of the wires

All frogs for the fixed trolley head are now designed on the straight under-running principle, the fish-belly type is practically obsolete Two different types of fixed frog are shown, having different methods of attachment to the trolley wire (fig 963) In one case the trolley wire fits into a groove in a long extension of the frog on the principle of an ear The trolley wire is then held under a clamp, and the wings of the ears hammered over upon the trolley wire.

In another type, which is more generally used, the frog is without ears, and the wire held in place by clamps In this case the clamp is rounded off so as not to cause the trolley wire to break by being continually bent over a sharp angle

With the introduction of the swivel-head trolley the above types of frogs and crossings were found to be unreliable, and various designs were made to secure certainty of action

The earliest type used was what may be described as the double-level frog (fig 966) This frog deflects the trolley wheel by guiding it along an inclined runner, until it has depressed the trolley wheel sufficiently for the flanges to clear the straight-through wire When running trailing from a branch the reverse action takes place When running trailing from the straight the trolley wheel pushes aside the guide runner of the branch and passes through, after which the guide runner is returned by means of a spring If in running facing it is desired to proceed on the straight track, it is necessary to pull a cord, which opens the switch and allows the trolley wheel to run through This type will work automatically one way facing, and both ways trailing, but it is open to the objection of all fish-belly frogs, that of not working well at high speed

Another type of frog for the swivel trolley is shown (fig. 967) These in general arrangement are something like the ordinary fixed frog, but instead of guiding the trolley wheel entirely by the groove, it does it part way by the groove, and in the centre by the flanges, a ridge being provided in one place and two grooves in another The fixed frog of this class will work automatically trailing, and can be arranged to run either way facing, but not both ways Where it is desired to work both ways facing, a movable frog is used whereby the grooves and tongue are set for the correct way This has to be done whether the frog is worked facing or trailing (fig. 968)

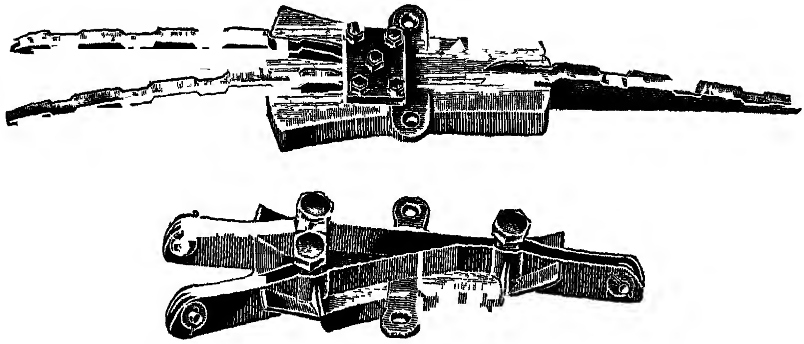


Fig 963 —Frogs for Fixed Trolley Head

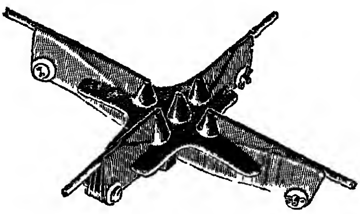


Fig 964 —Fixed Crossing for Rigid Trolley Head

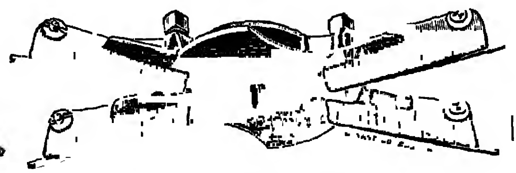


Fig 965 —Adjustable Crossing

Fig 966 —Double Level Frog

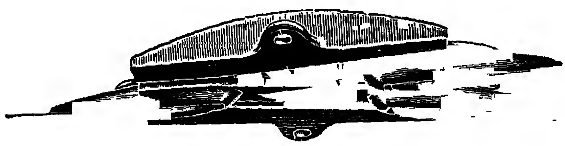


Fig 967 —Fixed Frog for Swivel Trolley

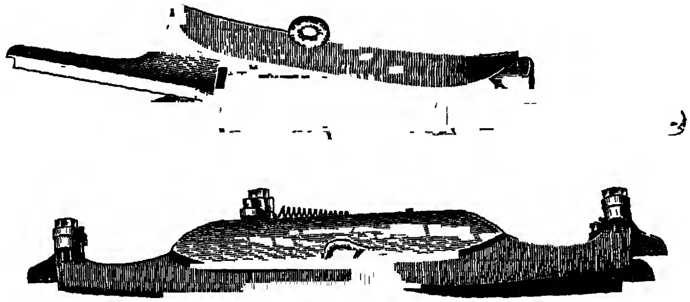


Fig 968 —Two Types of Mechanically-Moved Frogs

Frogs and Crossings

In this frog the use of both grooves and flanges as guides seem unnecessary, as if the frog has to be moved for each car, it is simpler to guide the trolley wheel by the groove alone

Grove's frog is designed to run automatically trailing and mechanically facing (fig. 969). Its chief distinctive feature is the parallel tongues which

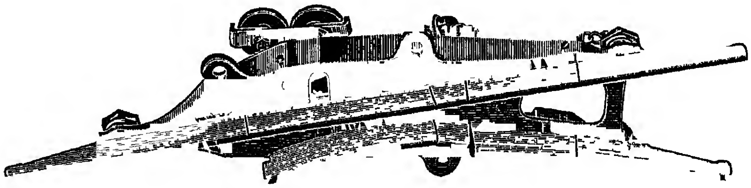


Fig 969 —Grove's Frog

ensure smooth running, it is somewhat complicated and expensive, but appears to give satisfaction There are a number of modifications in detail of the above Some of the movable frogs automatically set themselves for one track, unless held in position for the other wire. Some accomplish this by a balance weight, and some by a spring, and some remain fixed in the position last used A selection from various types can be used according to the service required of them.

Dawe's electromagnetic frog resembles fig 968, but is fitted with a solenoid, which is a shunt across the main circuit and which actuates the tongue of the frog. The shunt circuit is closed by a switch placed at a convenient point, and worked by hand or by the movement of the permanent-way switch tongue, or by a cam struck by a projection on the passing car This appears to be somewhat complicated, but has not been in use long enough to have an opinion formed of its merits

Crossings.—With the swivel-head trolley, the crossings must be set perfectly straight, that is, the trolley wires must not change their direction in passing through the crossings This can usually be accomplished by the proper adjustment of the pull-overs No adjustable crossings have yet been designed for the swivel-head trolley, and it is necessary to guide the wheel over the fixed crossings by both flange and groove as above described (fig 970) These can be obtained in a number of convenient angles, but it is the best practice to wait until the work is well advanced, and have them made to the exact angle required

A semi-adjustable crossing has been used with some success It resembles fig 965 in general design, but has the grooves for the flanges cut for one way, and after it is in position the grooves for the other direction are cut with a special tool.

Lightning Arresters.—It is necessary to protect the generators, motors, and the insulation of the line from effects of lightning The two former are always protected by the use of lightning arresters in the generating station and on the cars, and to protect the insulation of the line, lightning arresters are placed on a certain number of the poles. A lightning arrester for this purpose should be so designed that it is perfectly automatic, and should require no attention or resetting after it has acted.

These arresters are all based on practically the same principle, that is, that the lightning discharge will jump across an air-gap, or a gap of high resistance, which is sufficient to afford a high degree of insulation as against the ordinary dynamic current. When the insulation of the gap has been broken down by the static discharge, and an arc established, the dynamic

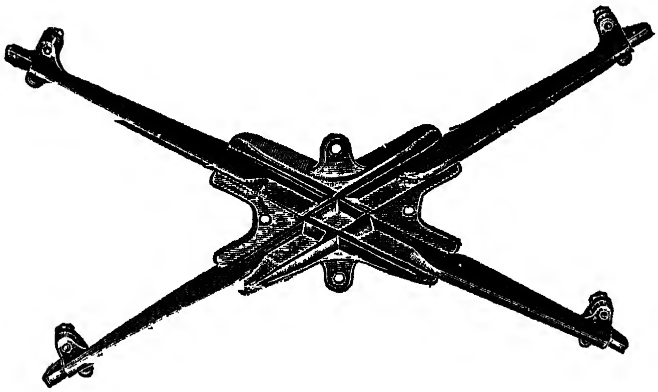


Fig 970.—Rigid Crossing for Swivel Trolley Head

current will follow and maintain the arc, so means must be provided for promptly extinguishing this arc In this latter particular lies the chief difference in the various makes of lightning arresters on the market

The four types which have been most largely used for tramway work are the Wurtz (fig 971), Garton (fig. 972), Shaw (fig 973), and Ajax (fig 974)

The Wurtz lightning arrester is probably the best on the market It operates as follows:—There is a gap of about ½ inch between the electrodes, and this gap is filled with wood slightly carbonized on the surface. The arc-extinguishing device is based on the principle that, to maintain an arc it is necessary that it should be fed with a metallic vapour, and the electrodes are made of special alloys which do not give off appreciable quantities of vapour This arrangement is entirely automatic and needs absolutely no attention

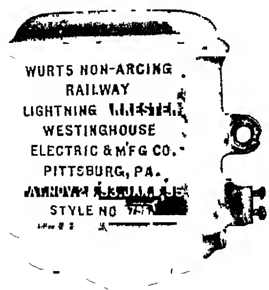


Fig. 971.—Wurtz Lightning Arrester

The Shaw lightning arrester is a pile of carbon discs separated by discs of insulating material, which extinguish the arc by dividing it into a number of short arcs which are not destructive

The Garton lightning arrester (fig 972) consists of an air-gap between carbon points H and J, a non-inductive resistance R in series with the gap, a magnetic coil F connected as a shunt across the resistance R. The arc is extinguished by the coil F, energized by the shunt current across R raising the armature E, which breaks the contact between E and H. The coil F also acting as a magnetic blow-out, immediately extinguishes the arc formed at this point. The arc

having been extinguished, the armature E falls back into place, and the lightning arrester is thus reset

The Ajax lightning arrester is designed on the magazine principle. The air gap is between small brass-wires enclosed in a small glass tube. Owing to its being sealed up, this air-gap can be made very small indeed The contact to these brass wires is made by two small carbon balls. When the dynamic current follows the static discharge to earth, it melts the small brass wires as it would a fuse This enables the small carbon balls to drop by gravity, and make contact with the next pair of wires, thus setting the arrester for another discharge

This arrester is automatic in action until exhausted, and it is refilled at a slight expense, but has the disadvantage that it must be inspected

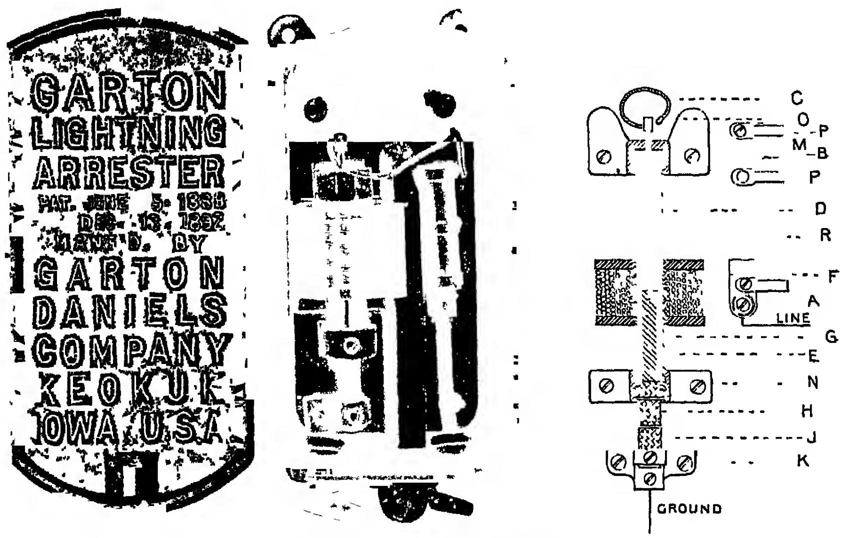


Fig 972 —Garton Lightning Arrester

periodically, there being no means of telling how many times it has been in action. Consequently a slight carelessness on the part of the linesman may leave the line without protection

To render the action of lightning arresters more certain, it is the usual practice, where possible, to place an impedance coil between the object to be protected and the lightning arrester tap. This impedance coil usually consists of ten or twelve turns of heavy wire about a wooden core

The number and location of lightning arresters required on a tramway must be governed by the frequency and violence of thunder-storms in the region For English practice it is generally considered sufficient to place one in each section of trolley wire, usually about the centre In fact many engineers now omit them altogether. In most cases it is not possible to arrange an impedance coil, but this is not absolutely essential, unless there are some local conditions that are not normal

In tropical or mountainous regions, each feeding-in wire should be provided with an impedance coil and lightning arrester, and if the feeding-

in points are a considerable distance apart, another lightning arrester should be placed between them.

The greatest care should be taken in providing suitable earth for lightning arresters Where steel poles are used, the earth-wire of the arrester can be connected to the pole by means of a rail bond, either solid or plastic, and the base of the pole connected to the tram rail by another

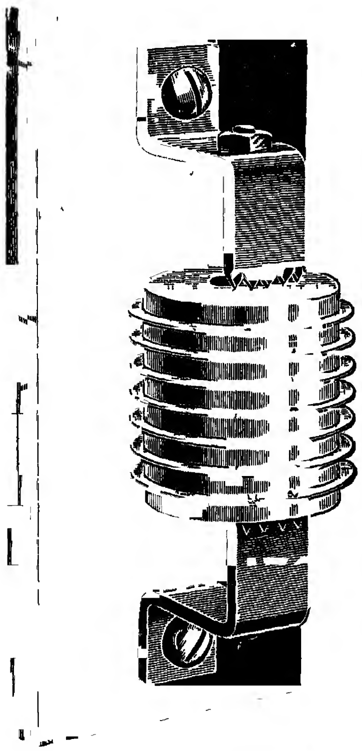


Fig 973 —Shaw Lightning Arrester

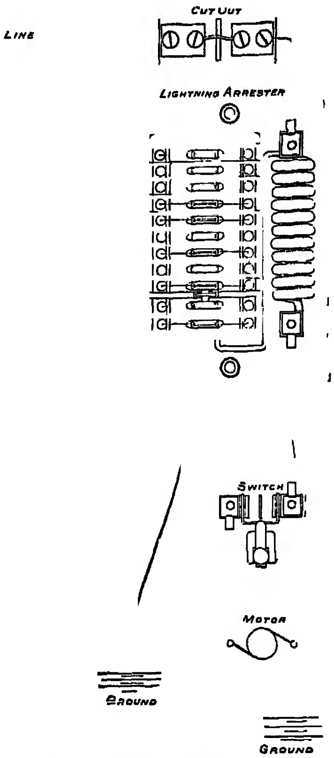


Fig 974 —Ajax Lightning Arrester

rail bond If the pole is of wood, the wire may be carried down the pole and out to the rail and bonded to the same If the permanent way is laid in very dry soil, or on wooden cross sleepers, it will probably be more desirable to use an earth-plate for earthing the arrester This earth-plate should be of liberal dimensions, an old car wheel makes a very good one The wire from the lightning arrester should then be bonded to the earth-plate, and the plate buried to a sufficient depth to obtain moist earth. A considerable quantity of charcoal or gas coke should be placed about the earth-plate to retain moisture.

TOOLS

The following tools and appliances will probably be found sufficient for most classes of work·—

1 reel wagon. 1 fixed tower wagon (fig. 975).
1 collapsable tower wagon (fig. 976)

12 to 24 sets of digging tools, each consisting of:—
- 1 digging bar, 8 feet 6 inches long, octagonal steel.
- 1 digging bar, 5 feet long
- 1 auger, 5 feet long, 15 inches over blade (fig 977).
- 1 auger, 7 feet 6 inches long, 15 inches over blade.
- 1 spoon (fig 978)
- 1 (grafting tool) spade with extra long handle.

12 picks
12 shovels, No 4.
4 rammers
4 soldering-irons (fig. 979).
2 soldering-pots
1 brazier or fire-devil
2 U-shaped clamps for soldering, 3 feet 6 inches between jaws.
Pliers, 7 inches and 8 inches; gas, 8 inches.
1 pipe-tongs.
1 pipe-cutter.
Trolley-wire cutters
2 hammers, 2-lb, and stone hammers.
2 sledges, 12-lb.
Chisels
Files
4 draw-vices Heavy P.O. pattern
Tool for putting up frogs (fig 980)
1 tool for putting up straight-line hangers (fig 981).
Spanner, Clyburn
2 hack-saws and blades.
1 plumb-line.
12 "come-along" clamps (fig 982)
1 special level for pole setting
1 right- and left-hand strainer and coupling-screws (fig. 983).
6 lbs of solder per mile of single wire
Steel-tape measure
2 ladders, rungs 9 inches apart, 24 feet long.
Acid jug and charcoal.
Vice-machine.
Vice-pipe
2 screw-drivers
2 sets $\frac{3}{4}$-inch blocks
400 feet of $\frac{3}{4}$-inch rope.
2 sets $\frac{1}{2}$-inch blocks
300 feet of $\frac{1}{2}$-inch rope
4 wire draw tongs (fig. 984).

A reel wagon usually consists of an ordinary heavy four-wheeled wagon, with a flat platform, and capable of carrying about two tons. Upon the platform is built a timber framework to carry a reel of trolley wire Attached to the framework is rigged a brake, usually applied to the rim of the reel in order to put a certain amount of tension on the trolley wire, and to prevent the reel from running out too fast. A roller guide is also

provided for the trolley wire to run out over. It is preferable to have the wagon as low as possible

If the line is a small one, it is possible to dispense with the reel wagon, and arrange the fixed tower wagon to carry a reel of wire, but it is much more convenient to have a separate wagon, and one can usually be hired for this purpose Any ordinary heavy lorry will do, and the framework is easily attached to the lorry platform

A very serviceable type of fixed tower wagon is shown (fig 975). This, as will be seen, consists of a very heavy body with a framework erected on top of it This framework carries a platform at a convenient

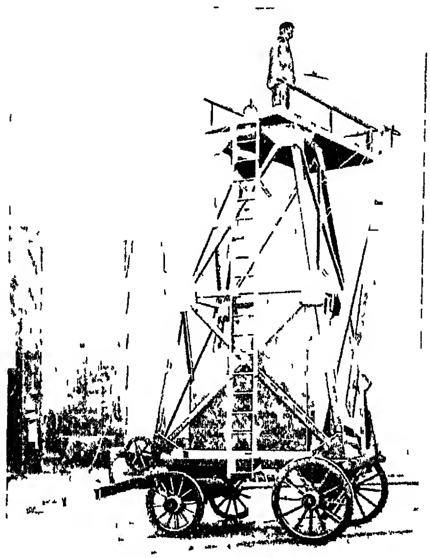


Fig 975 —Fixed Tower Wagon

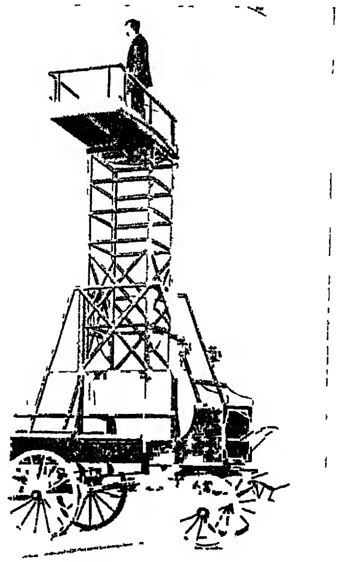


Fig. 976 —Collapsable Tower Wagon

height from the ground, depending somewhat on the height of the trolley wire, usually from 17 to 18 feet from the ground The platform is provided with a railing at the top and also at one side with a hinged extension, as it is sometimes necessary to work over the track or over the footpath without interfering with the traffic. The lower part of the framework is boxed in so as to form a lock-up store-room for tools and supplies The framework is also provided with a jib-crane, a winch, and tackle which is used for pole-setting Another arrangement of crane can be used by pivoting the jib-crane at the bottom of the framework, and holding it in position with tension-rods In this way the length of overhang may be made adjustable, which is sometimes convenient when the poles are not set exactly on the kerb.

A differential chain block and falls can be used in place of a winch. It is somewhat cheaper in first cost but much slower in action. The wagon should be provided with a powerful screw-brake Sometimes the tower wagon must be made variable in height, for if there are railway

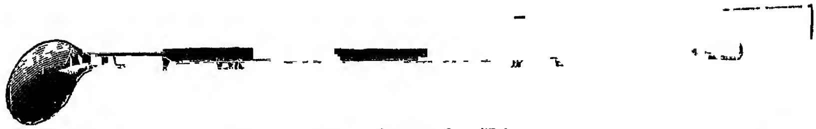
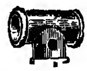


Fig. 978 —Spoon for Digging Post Holes



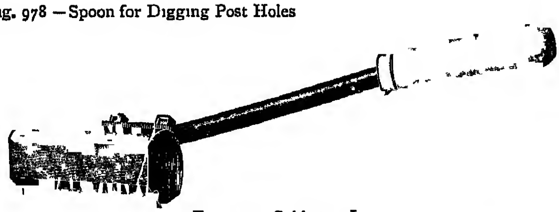


Fig 979 —Soldering-Iron

Fig 980 —Special Tool for putting up Frogs

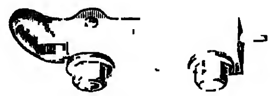


Fig 982.—"Come-Along" Clamp

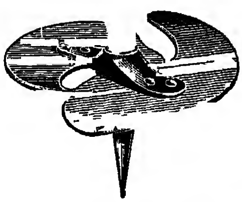


Fig 977 —Auger for Digging Post Holes

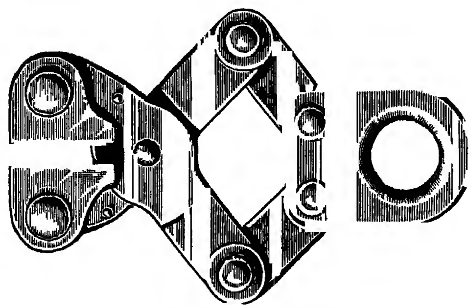


Fig 984 —Wire Draw-Tongs

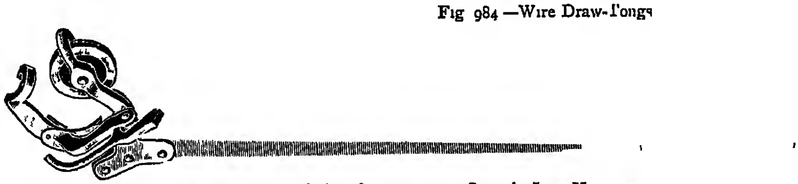


Fig 981 —Special Tool for putting up Straight-Line Hangers

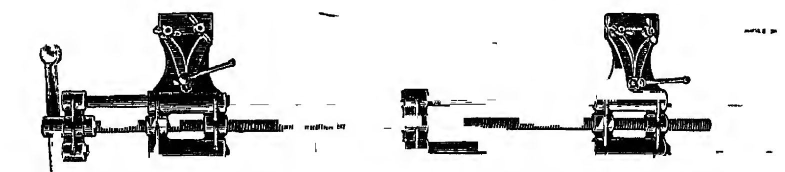


Fig 983 —Right- and Left-Hand Strainer and Coupling Screws for putting in Section Insulators

Overhead Construction—Tools

bridges crossing the lines, it may be difficult to get a tower of standard height underneath them, as these bridges are frequently under 16 feet in height This should be borne in mind in designing a tower wagon for any particular piece of work.

A very good type of collapsable tower wagon is shown (fig. 976), with a telescopic tower and a rotary and extensible platform at the top This type of tower wagon is more useful for emergency and repair work after the line is built than in the original construction. It is made as light as is consistent with strength, and therefore has not the storage capacity for tools, &c, of the type previously described. Being of much lighter build, and constructed for rapid transportation, it is not sufficiently stable for very heavy work

The quantity of digging tools required will depend upon the number of men it is intended to employ and the character of the ground to be excavated. The augers can be used in certain classes of soil with good effect, but are not of much use if gravel and stones are prevalent

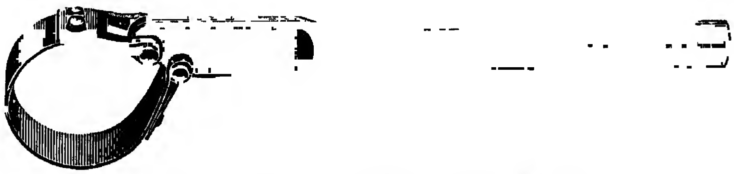


Fig 985 —Special Tool for screwing-up Insulating Bolts

The rammers are used for beating the cement into position after it has been placed in the holes, and it is often convenient to have one or more of them made semicircular or crescent-shaped

The soldering-irons should be as shown (fig 979), and usually weigh about 12 lbs apiece.

There should be a good assortment of files, and as they are very rapidly spoiled by the solder when used for dressing down the ears, a number of float-files should be provided for this purpose

The draw-vices should be of the heavy Post Office pattern with key and ratchet

A special tool for putting up frogs is shown (fig 980), but it is not at all essential, and unless there are a large number to be put in, would not pay

A special tool for putting up straight-line hangers is also shown (fig. 981). This is chiefly useful for span-wire work, and if there are a large number of spans, can be used with advantage, but the work can be done with a couple of wire draw-tongs and a light block and tackle. For bracket-hangers with the short spans, it is usually easier to slack off the tension at the end, when the hanger can be slipped in by hand and the span-wire tightened up again.

The steel-tape measure should be about one chain in length, and it is also advisable to have 100 feet of linen tape in addition.

The machine-vice should have about 5-inch jaws, and it should be so arranged that it can be readily attached to the heavy tower wagon.

A pipe-vice is extremely serviceable where there is any bracket-arm construction, and should be of sufficient size to take the pipe used for this purpose. It should also be fastened to the tower wagon.

This last, together with the pipe-tongs and pipe-cutters, may be omitted if span-wires are exclusively used

A special tool is also shown for screwing up the West End type of insulating bolt, which can be used to advantage in most cases (fig 985).

CHAPTER III

CONSTRUCTION

Setting Out Work.—It is first necessary to determine whether a swivel-head or rigid trolley wheel is to be used. This point having been decided, the next step is to set out the points of support, and then, if the engineer is free to make his own decision, to determine whether span-wire, centre-pole, or side-bracket suspension is preferable, and at what points

There are certain fixed points of support, such as junctions, sharp curves, terminals, &c, which serve as a basis to work on. These having been settled and located on as large a scale plan as is available, the spaces between them should be divided up into approximately equal divisions The maximum distance between supports allowed by the Board of Trade regulations is 40 yards This is about as far as it is wise to go in practice, supposing these regulations do not apply, but spans up to 45 yards may be occasionally used without detriment to the safety of the line

Upon the basis of 40-yard trolley spans it would be necessary to have forty-four supports to the mile, but in preliminary estimates fifty may be taken as a safe figure, and one easy to memorize and work with It will be found on the average to be more nearly correct than forty-four, on account of extra poles required at junctions. It will also be found in practice that, in endeavouring to space out the poles at regular 40-yard intervals, a certain number of them will fall in the centre of cross streets or in front of doorways, where it is impossible to place them As the length of trolley span cannot be increased, it is necessary to remove the pole to the nearest location that is satisfactory This then becomes a fixed point, and the poles between this and the last fixed point should be respaced and made as even as possible.

In laying out work it is best to calculate on 38-yard intervals instead of 40, as it is very often of the greatest convenience to be able to move a pole a few feet one way or the other to avoid pipes or underground obstructions without respacing the whole section. It should also be remembered that it may be more advantageous to slightly reduce the spacing of the poles on curves of large radius or on steep gradients than to use heavier poles, as the former method distributes the strain of the

curve over a greater number of insulators, which are the mechanically weak points in the construction.

The next step is to determine the size of the poles to be used under various conditions. Theoretically, it would be possible to calculate with a considerable degree of accuracy the strain to which each pole would be subjected. But it is not at all usual to have a survey of the tramways on a sufficiently large scale, and of sufficient accuracy, to do this, and in practice a few general rules, when coupled with a little judgment, will suffice In doubtful cases the engineer should put in a pole of ample strength if efficiency is the main consideration, and a light pole if economy in first cost is the governing factor, and take the chance of having to change it afterwards.

Some engineers prefer to use a great variety of sizes of poles, estimating, as accurately as their experience will permit, the strains at various points. Others will adopt but two, or at the outside three sizes, and use them exclusively In this latter case only the heavier types of pole are employed The first method is the most economical in regard to material, but requires a greater outlay for plans and preliminary work, and a greater amount of judgment and supervision in erection The second method usually allows a very ample factor of safety, and obviates the necessity of going into the strains on individual poles almost entirely. It also increases the ultimate length of life of the line The choice between these methods will be largely governed by the market prices of poles, but the general tendency now seems to be toward the second method

The location of the supports having been determined, the width of the roadway at these points should be ascertained, and also the distance from the kerb to the centre of the track or tracks, as these dimensions will determine the most suitable form of support to be used

The Board of Trade require a minimum clearance of 15 inches from the side of the car to the pole, and as the pole cannot be located within an inch or two, it is necessary to allow at least a foot for thickness of the pole. This makes it necessary to have, for centre-pole construction, a distance between the centre of the tracks equal to 3 feet 6 inches plus the extreme width of one car

In some instances the Board of Trade have accepted a smaller clearance than 15 inches where specially-designed cars were used.

It should be borne in mind that whatever type of trolley head is used, the closer and more nearly parallel to the centre of the track the trolley wire can be kept, the more smooth and satisfactory will be the working of the line With a rigid trolley head the departure from the centre cannot exceed about 2 feet, and preferably should be kept within 1 foot. And as side brackets of over 16 feet are not to be recommended, it limits the width of street upon which side-bracket construction can be used to about 30 feet for single track and 24 feet for double. If two rows of side brackets are used, one on each kerb, it can be worked with double track on a 40-feet street Beyond this width span-wires are absolutely necessary. But this form of construction, with two rows of side brackets, is not to be recommended with the centre-running trolley.

With the swivel-headed trolley the line can be made to work with the trolley wire as much as 15 feet from the centre of the track This extreme reach is not at all desirable, and it should be kept if possible within 6 feet, at which distance most excellent and satisfactory results can be obtained. This, with the use of a bracket not exceeding 16 feet in length, will work with single track in a 40-feet street, which is as wide as is often met with in English practice

In the case of double track with a 17-feet bracket and 6-feet reach, a single row of brackets may be used in streets up to 35 feet in width, which width is sufficient to allow the use of the centre-pole form of construction. If centre poles cannot be used, two rows of poles and brackets will work up to a width of 50 feet, beyond which it would be much more satisfactory to use span-wires

On straight and level track the side strain on the pole is readily determined either for span or bracket construction In centre brackets it is practically nothing In span-wires it can be determined by the application of the parallelogram of forces, assuming the weight to be half the weight of each of the adjacent trolley spans In side-bracket construction it may be determined by dividing the height of the bracket above the ground by the distance from the pole to the trolley wire in feet, and dividing the weight of the trolley wire in half of each of the adjacent spans by the result To this must be added the stress set up by the bracket itself, which will be the height of the bracket arm above the ground divided by the distance from the pole to the centre of gravity of the bracket, expressed in feet, and the weight of the bracket to be divided by this result, this is usually negligible

These strains must be determined as they will represent the minimum, and to them must be added the strains caused by the curvature of the line or the changes of gradient

The following sizes of poles will usually be found satisfactory It is assumed that in all cases two 00 trolley wires will be used, as this practice is now almost universal for both single and double track

On straight and level track, for centre and short side-bracket construction, 350-lb. poles may be used, but a smaller pole than 500 lbs is not recommended For span-wire work 500-lb poles may be used on streets up to 30 feet in width, if a moderate amount of dip in the span-wire is permissible. It is not recommended that for span-wire work poles of less than 700 lbs should be used for high-class and durable work

The above strains—500 lbs for bracket work and 700 lbs for span-wire work—should have a sufficient margin of strength to be used in all places where the curvature is not greater than the equivalent for a 10-chain radius, or where the brackets do not exceed 16 feet in length, or the gradients 1 in 20 If these figures are much exceeded, the strength of the poles should be increased. But in the case of span-wires the poles on the inside of the curve need not be increased, and might even be made lighter than suggested, as they do nothing to hold up the weight of the trolley wire. If 000 or 0000 trolley wire is used, the poles should be

increased to 700 and 1000 lbs. respectively. Any poles to which it is intended to attach anchors or bridles should be somewhat heavier, 1200 lbs being about the minimum for an anchor and 1000-lb. pole for a bridle.

Poles upon which it is intended to use section insulators are generally made heavier, as the larger diameter of pole gives more room for feeding-in wires Some engineers make it a practice to anchor the trolley wire both ways from a section insulator, but the tendency now is to omit this. Poles in the vicinity of junctions should also be made heavier, 1000-lb poles being the minimum for this class of work, but 1500- and 2000-lb. poles must be frequently used

If the strains in a junction are self-balancing, somewhat lighter poles may be used than could be otherwise. Where the gradients are long and severe, or on the crown of a hill, it is often advisable, and sometimes necessary, to provide anchor-poles and anchorages to take the strain caused by the tendency of the trolley wire to slide downhill, which tendency brings a very heavy strain upon the supports approaching the summit

POLE SETTING

Excavation.—The holes for the poles should be excavated to a depth of not less than 6 feet, and the size of the hole must depend upon the diameter of the pole and the nature of the soil If the soil is firm, and the streets are paved and afford a good support at the surface of the ground, a hole very little larger than the diameter of the pole will suffice If the soil is loose and sandy, or in made ground, it will be necessary to very considerably increase the diameter of the excavation in order to distribute the strain over a larger area

In some cases it may even be necessary to take special precautions to this end, namely, digging a trench 6 or 7 feet long at right angles to the direction of strain, and placing a piece of old rail 6 or 7 feet long at the back of the pole at the bottom, and a similar piece in front of the pole at the top, and embedding the whole in concrete As a general rule three times the diameter of the butt of the pole will be a sufficient diameter for the hole. Some support must be provided at the foot of the pole to prevent its sinking into the ground farther than was intended, and a flat stone or cast-iron base-plate may be provided for this purpose

Another method is to prepare concrete discs by running the concrete into moulds about 18 inches in diameter and 6 inches thick, and placing these discs, when they are thoroughly hardened, at the bottom of the excavation; or 4 inches of concrete may be put into the bottom of the excavation, and a piece of 2-inch plank, 1 inch square, placed on top of this The method adopted will depend to some extent upon the locality and the materials available

The poles should then be placed in the holes and given the necessary rake, and the whole of the excavation filled in with concrete thoroughly rammed. Care should be taken to finish off the top of

the concrete in a slightly conical form and higher than the level of the street, because there is a great tendency for water, both surface drainage and condensation from the pole, to collect at the junction between the iron and the concrete. This causes the pole to rust, and in a few years will materially weaken it at the point of greatest stress.

Concrete.—The quality of the concrete may to some extent be governed by the character of the soil and the strain to be expected If the earth is firm and the strain not excessive a cheap form of concrete may be used of eight or nine to one, and large stones may be employed, jammed in between the pole and the earth In fact, if sufficient care were used, under these circumstances the pole could be set without any concrete at all, but the difficulty of getting men to properly tamp in the soil renders the use of concrete of some sort a necessity.

If it is found necessary to increase the diameter of the excavation to distribute the strain, it then becomes necessary to use concrete of the best quality, not less than six to one.

Rake of Poles.—The rake of the poles must be determined in view of the strain they are to bear, and should be such that the strain will pull them up apparently straight, and should not, except in special circumstances, be greater than the diameter of the pole at its base. If it becomes necessary to increase this rake a heavier pole should be used, or the strain distributed among several poles The reason for this limitation is that a pole, when it gets its trimmings on, does not appear to be bent if the curvature does not exceed the greatest diameter There may be exceptional circumstances where it is not possible to follow out this rule, but they should be rare

It is preferable to give a pole too much rake than too little, for a pole that leans away from the strain does not convey an idea of weakness, while an inclination in the direction of strain gives it an appearance of falling over This is, of course, purely an optical effect, but is one which is most severely criticised by the general public Great care should be taken to give all poles visible from any one point an equal rake, and special attention should be given to poles that from their position can be readily compared with perpendicular lines of buildings

It is sometimes necessary, where several wires are attached to a pole, to set it with a rake in the direction of the resultant strains Where it is necessary to set a pole with the maximum rake it is frequently advisable to stay the pole in that position until the concrete has had time to set This can readily be done by the use of a collar clamped on the pole 4 or 5 feet from the ground, the collar being provided with three pivoted legs like a tripod

A special level for pole setting is provided with a cross bubble and a scale for measuring the inclination of the pole from the vertical, and is very useful in obtaining even results.

When the poles are being tested for acceptance it is advisable to plot a curve showing the deflection of the pole for different loads. This will be found useful in determining the exact rake to give to any pole.

Erection of Poles and Fittings.—The pole setting itself is usually done by means of a derrick attached to the tower wagon, but is sometimes done by sheer-legs, and occasionally by manual labour, assisted by forked poles of various lengths. The former method is preferable, and in most general use. One tower-wagon derrick, with a gang of one foreman and six or eight labourers, should set from thirty to forty poles in the course of a day, it being assumed that the poles have been delivered in the neighbourhood of the holes As forty poles represent some half mile of street, if they are set on both sides, or nearly a mile if set on one side only, one horse, cart, and driver will be needed to keep them supplied with concrete materials A sufficient number of men should be provided to excavate the holes as rapidly as the derrick gang can fill them, and the size of this gang will vary according to the character of the soil. The men usually work in pairs, and two men will, under average conditions, complete a hole in two hours.

The poles should be allowed at least seven days for the concrete to set before being subjected to any strain The bases, collars, and brackets should then be put on. In some cases the bases, if not excessively large, can be slipped over the pole before it is set, but if this is not practicable they will have to be lifted over the top by a light sheer-legs, and if not of great weight may be hoisted from a spar lashed to the framework of the tower wagon.

Collars are next slipped into position, and then the brackets are put on The tower and extension to the platform will be found necessary for this work The main portion of the bracket is lifted by the tackle into position, and the back half of the split collar is then put in place and the collar bolted together It is advisable to coat the inside of the split collar with a mixture of putty and white-lead to prevent moisture lodging between the collar and the pole This applies to all split collars either on the pole or bracket arm

The collar being in position the truss rods are next adjusted so that the bracket arm is at a slight angle above the horizontal, and are adjusted more accurately after the trolley wire is in position The remaining portions of the bracket are now fitted on In the case of span-wire brackets the method is the same, but as they are simpler and lighter, and have no truss-rod adjustment, they can sometimes be done from ladders or from a smaller tower wagon

The pole collars covering the joints should next be bedded in putty and white-lead, the finial put into the top of the pole, and preferably secured by a grub-screw. It is advisable that the top of the pole should be covered while the concrete is setting, as it is not desirable to have any quantity of moisture inside of the pole The base of the pole should be set concentric with the pole, bedded on cement mortar, and the annular space between the pole and the top of the base filled with melted lead, or a suitable metallic cement is used in some cases. This fixing of the pole bases is preferably left until after all the strains are on the poles.

If it is intended to use flexible bracket construction the flexible

suspension hangers and secondary insulation should be fitted to the bracket arm at its time of erection. In this case it is better to make up the flexible spans in standard lengths, with the insulators attached and hangers in place, in a convenient workshop, as this work can be done there more efficiently than in the street.

If rigid bracket suspension is to be used there is no particular advantage in putting up the hangers before the trolley wire is strung In span-wire work for straight-line insulators the span is first put up and the insulator sprung in by a special tool shown (fig. 981)

If curve hangers are to be used they should be attached to the span-wire. A "come-along" is then clamped to each end of the wire, and the span pulled up with a block and tackle or a P.O. vice, and the insulators plumbed for their proper position, keeping in mind that the strain of the trolley wire will pull them somewhat towards the inside of the curve When they have gotten to the desired location the ends of the span-wires are made fast to the Brooklyn strain insulators, and any fine adjustment is afterwards made by means of these turnbuckles. The line is then ready for the trolley wire.

Erection of Trolley Wire.—The most convenient method of erecting trolley wire is as follows.—

A reel of trolley wire, preferably of sufficient length to cover two or more sections, is placed on the reel wagon before described In addition to the driver two men will be required to attend to the brakes on the reel of wire, and if there is much traffic on the street a third man may be needed to attend the brakes on the reel wagon The trolley wire is then passed over the top of the tower wagon and made fast to one of the anchorages if it is desired to start from the terminus of a route, otherwise a temporary anchorage is placed at the point of starting If there are two rows of poles, the anchor is preferably of a **V** shape; if but a single row, the trolley wire is fastened to the end of a bracket arm to prevent its slipping away from the proper position, and the anchorage run to the next pole Where temporary anchorages are used it is usually advisable to run a guy from the top of the anchor pole to the next pole, and to this it should be secured as low down as can be done without interfering with the traffic.

The men required in connection with the tower wagon are. one foreman, one linesman and one helper on the platform, one driver, two linesmen, and five or six labourers

The P.O vices, block and tackle, "come-along" clamps, plyers, spanners, two ladders, &c., will be the tools required A sufficiency of 7/14 steel cable will be required, and also a number of stout wire **S** hooks of No 4 wire gauge

The reel wagon is now started slowly, and a moderate tension kept on the trolley wire as it is paid out The tower wagon maintains its position 150 to 200 feet behind the reel wagon, and as it comes directly under the bracket or span-wire the trolley wire is raised and hooked to the span with one of the **S** hooks above-mentioned. About every quarter of a mile, or at a greater or less distance according to the

traffic, a temporary anchorage is made. A "come-along" clamp is placed on the trolley wire, and an anchorage run out to the next pole ahead, and the trolley wire pulled up approximately into position, and the reeling-out process then proceeds. It is advisable to send a lineman ahead with ladders, to prepare the anchorages at the proper points, so that the tower and reel wagons need not be delayed.

Upon reaching a curve of sharp radius it is always best to anchor. The trolley wire is then carried around the curve, preferably with three or four mechanical ears, which are pulled off to convenient poles drawing the trolley wire into its approximate position. Care must be taken to leave slack enough in the trolley wire, as it is easy to work the slack through as the soldering-in proceeds, but is hard to work it back. At the far side of the curve another anchorage is put on, to pull against and prevent the strain of a long section of trolley wire from coming on the curve.

The stringing out now proceeds in a similar manner until all the trolley wire is run out, when a final anchorage is put in to hold it in position. Unless there are some special traffic difficulties to deal with, or an exceptional number of curves to anchor, a mile of trolley wire should be run out in two or three hours. If two trolley wires are to be used it is preferable to go back to the beginning and run out a second wire before soldering in. In fact, in many instances four miles of trolley wire may be run out in a day and temporarily anchored up. This enables the reel wagon and its crew to be used to the greatest efficiency.

In the first pulling up, above described, the wire should be fairly tight, as otherwise, when the final pulling up comes, too much slack is carried forward, and the trolley wire drops down and interferes with the traffic. The final pull-up before soldering in may be done in lengths of as much as ½ mile if the line is moderately straight, but it is impossible to pull around a sharp curve.

Tension on Trolley Wire.—The exact degree of tension to be put on the wire will depend to a great extent on the temperature at the time the work is carried out. The deflections allowable at different temperatures, and for various lengths of span, are shown in Table D. The strains resulting from these deflections may be determined from Table C. If the supports were absolutely rigid the deflections in Table D would have to be largely increased for the lower temperatures. In practice the curves of the line allow the strain caused by the shortening of wire, due to a decrease in temperature, to be taken up by the bending of the poles. On lines with many curves the deflections shown in Table D might be decreased somewhat with safety, and on very long straight lines a slight increase would be advisable.

The following table will be found useful for determining the strain on the centre of the span:—

TABLE C

Strains at Centres of Spans Resulting from a Given Deflection

(John A Roebling's Sons Company)

Deflections in Decimal Parts of Spans

Spans in Feet.	001	.002	003	004	.005	006	007	008	009	010	015
	Multipliers										
10	1 250 001	625 003	416 671	312 506	250 008	208 343	178 583	156 263	138 903	125 016	83 358
20	2 500 003	1 250 006	833 343	625 013	500 016	416 686	357 166	312 526	277 807	250 033	166 716
30	3 750 005	1 875 01	1 250 015	937 52	750 025	625 03	535 749	468 79	416 711	375 05	250.075
40	5 000.006	2 500 013	1 666 686	1 250 026	1 000 033	833 373	714 332	625 053	555 615	500.066	333 433
50	6 250 008	3 125 016	2 083 358	1 562 533	1 250 041	1 041 716	892 915	781 316	694 519	625 083	416 791
60	7 500 01	3 750 02	2 500 03	1 875 04	1 500 05	1 250 06	1 071 498	937 58	833 423	750 1	500 15
70	8 750.011	4 375 023	2 916.701	2 187 546	1 750 058	1 458 403	1 250 081	1 093 843	972 327	875 116	583 508
80	10 000.013	5 000 026	3 333 373	2 500 053	2 000 066	1 666 746	1 428 664	1 250 106	1 111 231	1 000.133	666.866
90	11 250.015	5 625 03	3 750 045	2 812.56	2 250 075	1 875 09	1 607 247	1 406.37	1 250 135	1 125 15	750.225
100	12 500 016	6 250 033	4 166 716	3 125 066	2 500 083	2 083 433	1 785 83	1 562 633	1 389 038	1 250.166	833 583
110	13 750.018	6 875 036	4 583 388	3 437 573	2 750 091	2 291.776	1 964 414	1 718 896	1 527 942	1 375 183	916 941
120	15 000.02	7 500.04	5 000 06	3 750 08	3 000 1	2 500 12	2 142 997	1 875 16	1 666.846	1 500 2	1 000 3
130	16 250.021	8 125 043	5 416 731	4 062 586	3 250.108	2 708 463	2 321 58	2 031 423	1 805 75	1 625.216	1 083 658
140	17 500 023	8 750 046	5 833 403	4 375 093	3 500 116	2 916 806	2 500 163	2 187 686	1 944 654	1 750.233	1 167 016
150	18 750 025	9 375 05	6 250 075	4 687 6	3 750 125	3 125 15	2 678 746	2 343.95	2 083 558	1 875 25	1 250 375
160	20 000 026	10 000 053	6 666 746	5 000 106	4 000 133	3 333 493	2 857 329	2 500 213	2 222 462	2 000 266	1 133.733
170	21 250 028	10 625 056	7 083 418	5 312 613	4 250 141	3 541 836	3 035 912	2 656 476	2 361 366	2 125 283	1 417 091
180	22 500 03	11 250 06	7 500 09	5 625 12	4 500 15	3 750 18	3 214 495	2 812 74	2 500 269	2 250 3	1 500 45
190	23 750 031	11 875 063	7 916 761	5 937 626	4 750 158	3 958 523	3 393 078	2 969 003	2 639 173	2 375 316	1 583 808
200	25 000 033	12 500 066	8 333 433	6 250 133	5 000 166	4 166 866	3 571 661	3 125 266	2 778 077	2 500 333	1 667 166

Rule —To find strain in pounds on wire of given span and deflection multiply the numbers column answering to span and deflection by the weight per foot of wire

TABLE D

(John A. Roebling's Sons Company.)

Temperature in Degrees Fahrenheit at time of erection	Spans in Feet.					
	75	100	115	130	150	200
	Sag in Inches					
− 30	1	2	$2\frac{1}{2}$	$3\frac{3}{8}$	$4\frac{1}{2}$	8
− 10	$1\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{3}{4}$	5	9
10	$1\frac{1}{2}$	$2\frac{3}{8}$	$3\frac{1}{2}$	$4\frac{3}{8}$	$5\frac{3}{4}$	$10\frac{1}{4}$
30	$1\frac{3}{4}$	3	4	$5\frac{1}{8}$	$6\frac{3}{4}$	12
60	$2\frac{1}{2}$	$4\frac{1}{4}$	$5\frac{1}{2}$	7	9	$15\frac{3}{8}$
80	$3\frac{1}{8}$	$5\frac{3}{8}$	7	$8\frac{5}{8}$	$11\frac{1}{4}$	$18\frac{3}{4}$
100	$4\frac{1}{2}$	7	9	11	14	$22\frac{1}{4}$

Hard-drawn copper wire has a tensile strength of from 45,000 to 68,000 lbs per square inch, according to the degree of hardness—50,000 lbs may be taken as a fair average for the sizes in most common use

Annealed copper wire has a tensile strength of from 32,000 to 36,000 lbs per square inch

The following table will give the strengths of both hard-drawn and annealed copper wire for the sizes of trolley wire most frequently used —

B & S. Gauge	Diameter, inch	Strain, lbs	
		Hard-drawn.	Annealed
0 000	4600	8310	5650
000	.4096	6580	4480
00	3648	5226	3553
0	.3249	4558	2818

In calculating the maximum strain to which a trolley wire should be subjected, it must be borne in mind that, although the wire is hard-drawn, the soldering on of the ears anneals it at points Therefore the maximum strain to which the wire should be subjected at its lowest temperature should leave a margin of safety. It is not usual practice to have this strain exceed about two-thirds of the breaking strain of annealed copper wire. In pulling up before soldering in, it is advisable to use a dynamometer, as otherwise it is extremely difficult to get an even tension on all parts of the line.

Soldering on Ears.—The trolley being pulled up to the required tension, the next step is to put on the ears and insulators. The soldered-on ear is now standard for high-class work, and the sweating-on is done somewhat as follows:—

The exact position of the ear is marked on the trolley wire A heavy U-shaped cramp (fig 986) is then clamped to the trolley wire, the U standing in a vertical position above the wire The cramp should be heavy enough to relieve the portion of trolley wire being heated for soldering from practically all strain The portion of wire to receive the ear should then be well tinned, care being taken not to have the soldering-iron too hot An acid flux may be used, but it should be thoroughly-well cut. The ear is now placed in position, the cramp is given a half-turn and brought directly underneath the trolley wire, and the ear held in position by gas plyers. The lips of the ear are then carefully hammered down on to the trolley wire so as to force the wire solidly into

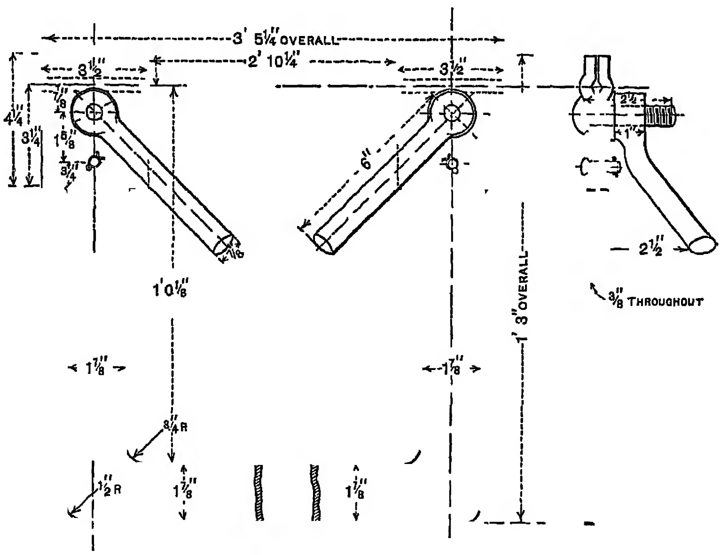


Fig 986 —Cramp for holding Wires while Ears are being soldered on

the groove The wire and ear are then heated with a soldering-iron, and the solder run in so as to completely fill the groove in the ear The ear and wire may be cooled with water and all the acid washed off The wings of the ear should then be dressed down with a file, and any surplus solder removed. It is of the greatest importance to get a perfectly smooth surface for the trolley wheel to travel on The lips should also be dressed down fine at the ends, so that the trolley wheel may have an easy entrance

Considerable care should be used in handling the trolley wire, both in the putting on of the cramp and in the dressing down, not to scratch the surface As in hard-drawn wire, the strength given by the drawing is largely in the surface, and a comparatively shallow scratch seriously weakens the wire. This also applies to the "come-along" cramps, and under no circumstances should a P.O. vice or a draw-tongs be put directly on the wire.

The ear being now finished, the cramp may be removed, and the

ear should stand vertically on top of the trolley wire. The insulating bolt is now slipped through the hanger and screwed into the ear, and the cap of the hanger screwed into place. The exposed portion of steel of the insulating bolt should be painted with P. & B. compound, in fact, sometimes the whole insulating bolt is dipped in P & B., and while wet slipped into the hanger and screwed up. If mechanical ears are used the cramp is not required, they being simply fastened into position and the insulating bolt put in They are very much easier and less expensive to erect, and do not weaken the wire by annealing it at each ear, but they cannot be arranged to run without sparking, and in time give trouble, the copper crystallizing and breaking off by reason of vibration at the ends of the ear

Section insulators are put in in much the same manner, except that it is necessary to use a wire-stretching device (fig 983) in most cases, as the length of the break does not give a sufficient amount of trolley wire to turn up through the insulator and go under the clamp It is usually necessary to get 2 or 3 inches more trolley wire at these points. Some engineers prefer to put the section insulators in before soldering in the ordinary work between, and the practice has much to recommend it where the line is fairly straight It is somewhat more expensive, owing to the extra amount of shifting of the gang and tower wagon required

The men necessary for soldering in are a driver, foreman, two linesmen, one man to attend the fire-devil and soldering-irons, and one or two labourers A melting-pot may be used in place of the soldering-irons, the melted solder being poured over the wire or ear with a ladle until it has heated it to the required degree. This method has some points of advantage It is easier to judge of the temperature of the solder, so there is less danger of overheating the trolley wire A gang of men as above described should solder in about a mile of straight single track per day, and should put up about 3 miles of line with mechanical ears.

Curves and junctions add greatly to the difficulty of the work In laying out a curve it is advisable to finish the line on one side up to the curve, and place the mechanical ears referred to in as nearly as possible their correct position. The lengths of the pull-off wires are then adjusted, and the curve pulled from the other end to the approximate tension

The positions of the ears having been thus determined the curve should be slacked off and the permanent ears sweated on, the insulators, hangers, and pull-offs put in place, and the curve again pulled up and adjusted to its final position. Care must be exercised that the strain on any pull-off is not greater than the insulating bolt can bear without bending, and that the pull-off wire does not make too sharp an angle with the trolley wire, in which latter case there would not be clearance for the trolley wheel between the wire and some part of the hanger

Where the pull-off wires from a curve cross the trolley wire on the

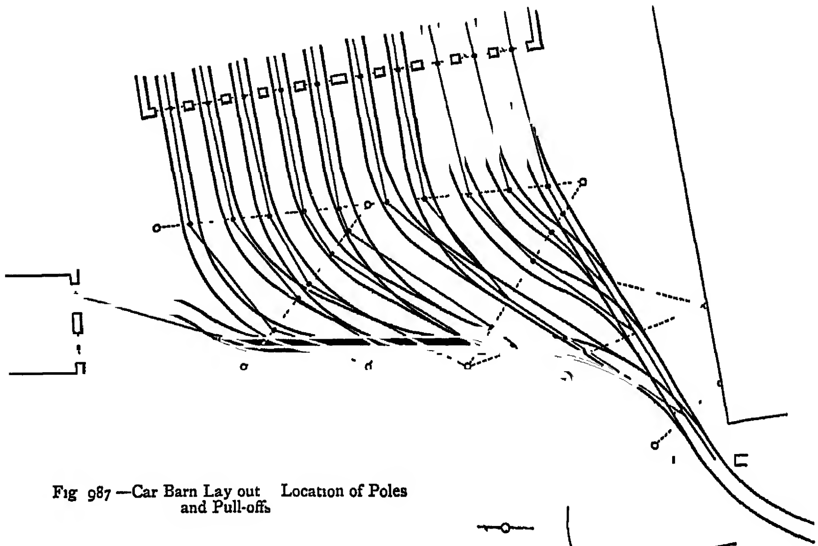


Fig 987 —Car Barn Lay out Location of Poles and Pull-offs

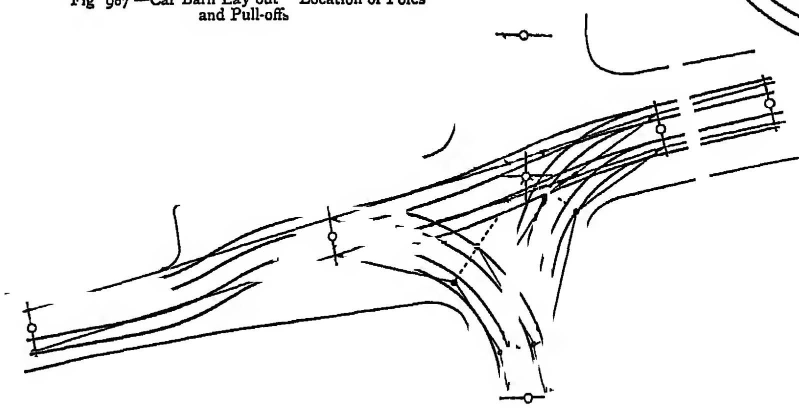


Fig 988 —Double-track Crossing with V Junction. Location of Poles and Pull-offs

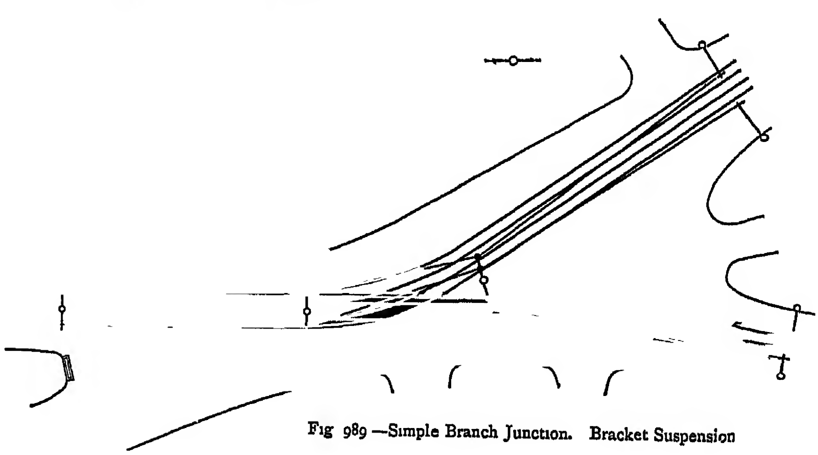


Fig 989 —Simple Branch Junction. Bracket Suspension

main line it is necessary to use an insulator that will prevent their coming in contact from the swaying of the line. The insulator shown in fig. 952 is more suitable for this than the ordinary type of straight-line or curve hanger, as it is much lighter. In laying up a Y-curve the strains can often be made to balance each other. In some cases where a number of pull-offs run to one pole it is better to run them into a bull-ring at a convenient point, and from the bull-ring run a single heavy cable to the pole. Several typical curves and junctions are shown (figs. 987, 988, and 989), with the usual methods of pulling into position.

FROGS AND CROSSINGS

Frogs—In setting frogs for the centre-running trolley it is necessary to locate them with considerable exactness The diagram, fig 990, shows the principle by which these frogs are made to work The frog is set at D, slightly out of centre as to the straight-through track in

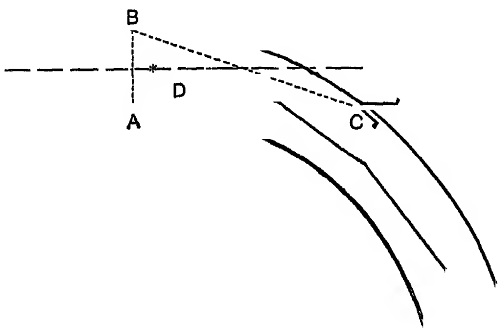


Fig 990

the direction of the branch line This gives a tendency for the trolley wheel to drag against the side of the frog and follow the straight line. The frog must also be given a certain amount of lead—that is, it must be placed some distance in advance of the points in the permanent way A B, so as to bring the frog out of centre in relation to the branch track towards the outside of the curve, or in the centre of the triangle A B C. The exact amount of the lead will be determined by the radius of the curve, the height of the trolley wire from the rail, height of car, and length of trolley arm, and also the superelevation of the outside rail of the curve.

If both rails are perfectly level the position of the frog would be approximately as shown, but the frog should not be secured in place until it has been tried, and a portion of the trolley wire on the branch line is generally run through the frog and coiled up so as to enable the lead to be reduced if desired

The frogs are usually provided with eyes for the attachment of guy-wires by which the frog can be pulled into its exact position. The superelevation of the rail is a feature that is often overlooked In the setting of a frog, where the outer rail has a 1-inch superelevation, the line being 21 feet in height and the gauge standard, the frog must be 4 or 5 inches farther towards the inside of the curve

Frogs that are to be set for the swivel-headed trolley are set very much on the same principle, but more latitude as to the exact position is allowable There is no necessity for any lead on the straight-through track, but if it is intended to work with a fixed frog a much stronger lead will be required for the branch line

If a mechanically-worked frog is used the trolley wheel will take it in almost any position in which it can be reached. But it is not advisable to strain the following capabilities of the swivelling trolley to their utmost, and it is therefore wise to follow the general rule as far as circumstances will permit, and the principle will apply even though the frog is set at a considerable distance away from the centre line of the track

There are two methods of attaching the frog to the trolley wire (fig 963) — one by soldering, in a similar manner to the attachment of an ear; the other by passing the trolley wire under a suitably-designed clamp with curved jaws, the curves being so designed that the pressure of the trolley wheel does not bend the trolley wire over a sharp angle and thus cause it to break off

The second type is distinctly preferable, as it is more easily erected, and its position more easily adjusted after erection This last is a great convenience, for, owing to the stretching of wires or slight movement of some of the poles, it may be necessary to adjust the position of the frog after the line has been in operation for some time

It is always necessary to run the frogs and crossings with some caution, as, owing to their extra weight, they form rigid spots in the line, which, if run at speed, tend to throw the trolley wheel downwards and clear of the wire. In this respect frogs which guide the trolley wheel by a groove as well as a flange can be worked at much higher speed than those that trust to the flanges alone

Crossings.—These are attached to the trolley wires in a similar manner to that described for the frogs In laying out the pull-offs around the junctions, they should be so arranged that the crossing comes between two of them, and neither trolley wire changes its direction at the crossing It is best to put up the junction and pull it into its final position before putting in the crossing An adjustable crossing may then be put in in the case of centre-running trolley, and in the case of the swivel trolley the crossing may be cast to the exact angle, or it may be possible, by a slight adjustment of the pull-offs, to bring the trolley wires to one of the standard angles for which these crossings are usually stocked. Or the semi-adjustable crossing already described may be used. There are a large number of insulated crossings available should it be desirable to insulate one trolley wire from the other, but these should be avoided whenever it is possible, as they are apt to give trouble in

practice. There is very little necessity for their use in England, as it is seldom that lines belonging to different owners cross each other, and when they do it is usually at nearly right angles, which type of insulated crossing is the least troublesome.

CHAPTER IV

SWITCHES AND SWITCH-BOXES

Owing to the necessity for dividing the trolley wire up into sections, to comply with the Board of Trade regulations and for convenience in working, a certain amount of switch-gear has to be provided, which must be suitably protected from the weather. Where there are no feeders to be broken, and where it is merely a

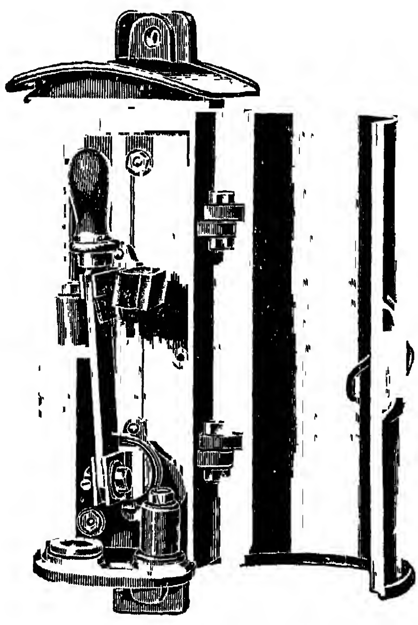


Fig 991 —Switch-Box for attaching to Pole

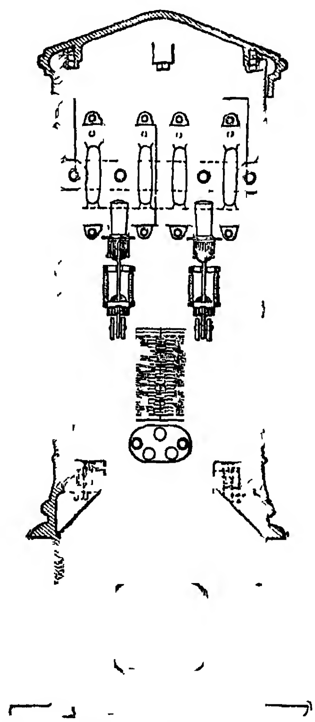


Fig 992 —Tramway Feeder Pillar

case of bridging a break made in the trolley wire by the section insulator, a pole-box may be used as shown, fig. 991. This can, however, be made to hold but a single switch, and it cannot be made ornamental, and its use is generally restricted to outlying and suburban lines.

The most usual form of switch-box is a cast-iron box, a good deal like a letter-box in appearance, from 3 to 4 feet high and about 18 inches in depth, and of sufficient width to contain the requisite number of switches, which are usually mounted on a marble or slate panel (fig. 992).

These boxes are generally provided with weather-proof doors at front and back, with brass hinges and locks. The marble panel is placed vertically, one door giving access to the switches and the other to the connections at the back The box is generally set about 18 inches in the ground, the bottom part forming a chamber into which are run the cable ducts for the feeders

Another type of box is sometimes used similar to the above, with the exception that the panel carrying the switches is placed horizontally, and access is obtained by raising the top of the box, which forms a lid. It has the drawback, however, that when necessary to use the switches in wet weather there is a liability to short circuits from the wet, as raising the lid exposes the switches It also occupies rather more room on the foot-path than the other type, in which the height may be increased and two or more tiers of switches employed The switches employed for this class of work should be of very substantial construction, as they may often be handled by untrained men They should be of the quick-break type, and of not less than 300 amperes capacity.

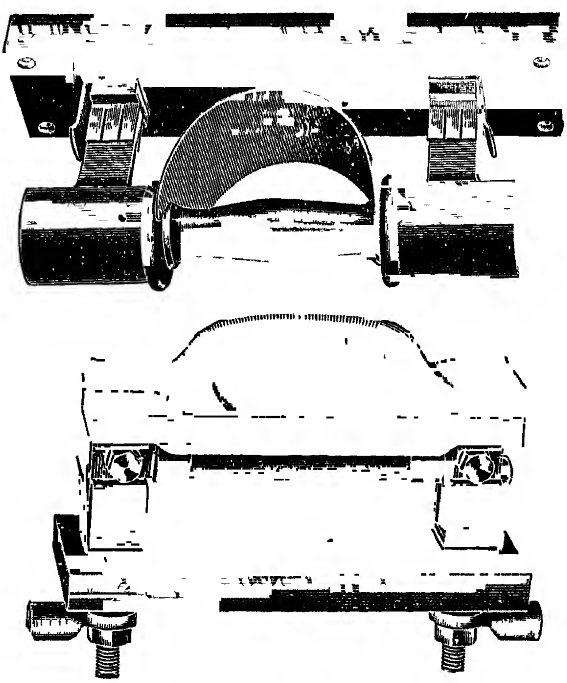


Fig 993—Fuses for Feeder Pillars

In some cases it is necessary to use a large number of switches, as many as twelve or fourteen are occasionally placed in one box, and the switch-board must sometimes be provided with one or more bus-bars, usually placed at the back It is a good plan to have the connections at the back of the board indicated on the front for ease in manipulation. Terminals for the reception of the cables should be detachable and numbered, so that if the cables are detached for testing there may be no error in connecting them up.

In many cases fuses of various designs (fig 993) are used in the switch-boxes, and in some few instances magnetic circuit-breakers have been employed, the object being to automatically cut out any section in which there is a fault. It is doubtful if these fuses are of any real value or convenience, because, unless they are of greater capacity than the feeder circuit-breakers in the generating station, they will act first under an

exceptionally heavy traffic load, and in so doing are likely to cause a troublesome delay at a time when delay is especially injurious. The only way of making them at all useful in locating a fault, assuming them to be of greater capacity than the feeder circuit-breaker on the switch-board, is to hold the feeder circuit-breaker in until the proper one goes. This perhaps helps to localize the fault, but the extra size and cost of the switch-boxes to accomplish it is a considerable item.

Lightning arresters are usually provided on the wires coming in from the trolley wire, and choke-coils in the feeder cables. Sometimes considerable trouble is experienced from the boxes sweating, particularly where a drawn-in system of feeders is used In consequence of this, iron and steel should be avoided as much as possible in the interior of the boxes, and provision made for ventilation It is advisable to fit a diaphragm across the bottom of the box a few inches from the street level. This can be made of wood and fit closely around the cables, and then covered with a ½-inch layer of bitumen or other suitable compound, which will make the box gas-tight in reference to the ducts Ventilation should be provided below this diaphragm and above the street level

The pilot wires for measuring the fall of potential in the rail return are usually brought into the switch-boxes, and terminals provided, so that the test wire may be divided into sections It is a great convenience, when operating the line, if a coloured diagram of the feeder system is placed in each switch-box, usually on inside of the front cover, and it is also advisable to have the various switches clearly labelled, and, if possible, brief instructions as to their use

A certain number of dummy switch-blades are generally provided to be slipped into the jaws of an open switch, to indicate that there are men working on that section, or that for some other reason it is not to be used

In a number of cases telephones have also been placed in these boxes, so that communication could be had with the generating station or the office Sometimes these telephones are fixed, and sometimes only terminals are provided, a portable instrument being used. Whether it is advisable to fit these boxes with telephones will have to be decided according to local conditions, but in practice, in most cases, they will not be found particularly useful, as the tendency of the box to sweat, above referred to, causes them to get out of order unless they are frequently and regularly inspected. If kept in order they are useful in localizing a fault

The switch-boxes are usually placed close to the pole through which it is intended to feed the trolley wire. Occasionally they are placed touching the pole, and a short length of pipe inserted between them to carry the feeding-in wires More frequently they are placed 3 or 4 feet from the pole, and a small drawing-in box or chamber provided between the box and the pole Sometimes they may be set in a convenient corner some yards away.

Feeding-in wires from the switch-boxes to the trolley wire are usually made up of very fine strands of copper, to be as flexible as possible. They are preferably insulated with rubber, and should always be lead-covered They should have a sectional area equal to the trolley wires they feed, but

this is not absolutely essential. As their length is short, the fall of potential caused by wires of small section is negligible, and as the space through which they have to be carried is restricted a small cable is sometimes more desirable

There are several methods employed in running the feeding-in wires from the pole to the trolley wire In some cases a small cross-arm of the same length as the distance between the binding-posts on the section insulator is attached to the pole, and provided with insulators at each end. The wires are then run straight from these insulators to the binding posts on the section insulators, and if the trolley is not far distant from the pole no intermediate supports are necessary, and the appearance is neat

Another method (fig 994), which is perhaps more generally used, is to bring the feeding-in wires through the pole at a slightly higher level than

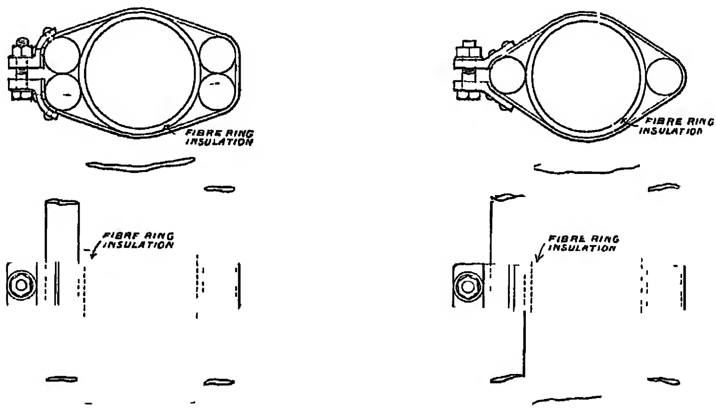


Fig 994

the bracket or span-wire, and bind them closely in to the pole and the bracket arm or span-wire, until the section insulator is reached, when the wires branch out to their respective terminals The feeding-in wires should always be provided with an insulating bushing where they enter and leave the pole, and the ends should be carefully sealed to prevent moisture from getting into the cable

The arrangements for switches and feeding-in wires will depend largely on the method adopted for dividing the trolley wire into sections. The ideal arrangement of these sections is to have each section fed normally from one point, but capable of being fed from two or more points, which, if possible, should be connected to different feeders

It is now the usual practice to use two trolley wires, both for single and double track, in some cases these are electrically connected together, and in others insulated from each other. By connecting them together a distinctly more efficient use is made of the copper in the trolley wire for the purpose of transmission, and in so doing the number of switches in the switch-box and the number of feeding-in wires is considerably reduced But if there is a fault in either wire, it disables both. By keeping them insulated the wires can be worked separately, and an absolute block in the

service prevented The method to be adopted must be decided according to whether economy of first cost or certainty of working is to be considered

If the trolley wires are to be insulated from each other, it is best to treat each junction as a separate section (figs. 988, 989), that is, by placing section insulators in the approaching lines, as close to the junctions as possible. This method will avoid the use of insulated frogs and crossings, which are cumbersome, unsightly, and not too certain in operation. If this method is adopted, it will give certain fixed points having gaps of a fixed length between them.

These gaps will then be divided up as nearly as possible into the ½-mile sections required by the Board of Trade, who will usually, if approached, allow this length to be exceeded by a few yards, which may be very convenient if the fixed lengths do not divide nicely into ½-mile sections In cases of very heavy traffic it may be necessary to reduce the sections below ½-mile, as the Board of Trade do not allow more than 300 amperes to be delivered by any one feeder.

CHAPTER V

SPECIAL CONSTRUCTION AND SAFETY DEVICES

Car Barns, Bridges, &c.—In car barns and under bridges, where there is a metallic structure or the head-room is small, it is usual to erect an inverted wooden troughing, 11 or 12 inches in width and 3 or 4 inches in depth This troughing is secured to the roof or bridge girders, and to it are bolted bridge hangers (fig 942) at intervals of 10 or 12 feet In the car barn this troughing is wholly unnecessary, and is probably a survival of the earlier practice, when uninsulated trolley poles were in use It is a source of danger rather than of safety, as it is very easy to place the trolley wheel on the troughing, and against the wire but not on it In which case the car runs along until clear of the barn, when the trolley flies up and gets entangled with the overhead work, which is usually complex at the car sheds A better method is to put a span-wire across the sheds at each principal, and put in an ordinary straight-line hanger The span-wire should be stayed to the truss-rod of the principal about every 20 or 30 feet This gives a flexible and easy-running arrangement which is much less in the way than the troughing

In the case of bridges passing over the line it is somewhat different, as the head-room is often much restricted, and it is necessary to run the trolley wire as close as possible to the under side of the bridge. Some device is necessary to prevent the trolley wheel from pressing the wire up against the bridge and causing a short circuit The usual method of bolting the bridge hangers directly to the troughing is not wholly satisfactory; owing to the expansion of the wire between the rigid points of support it puts a good deal of slack into the short spans generally used.

If the hangers are given a slight amount of play longitudinally, the

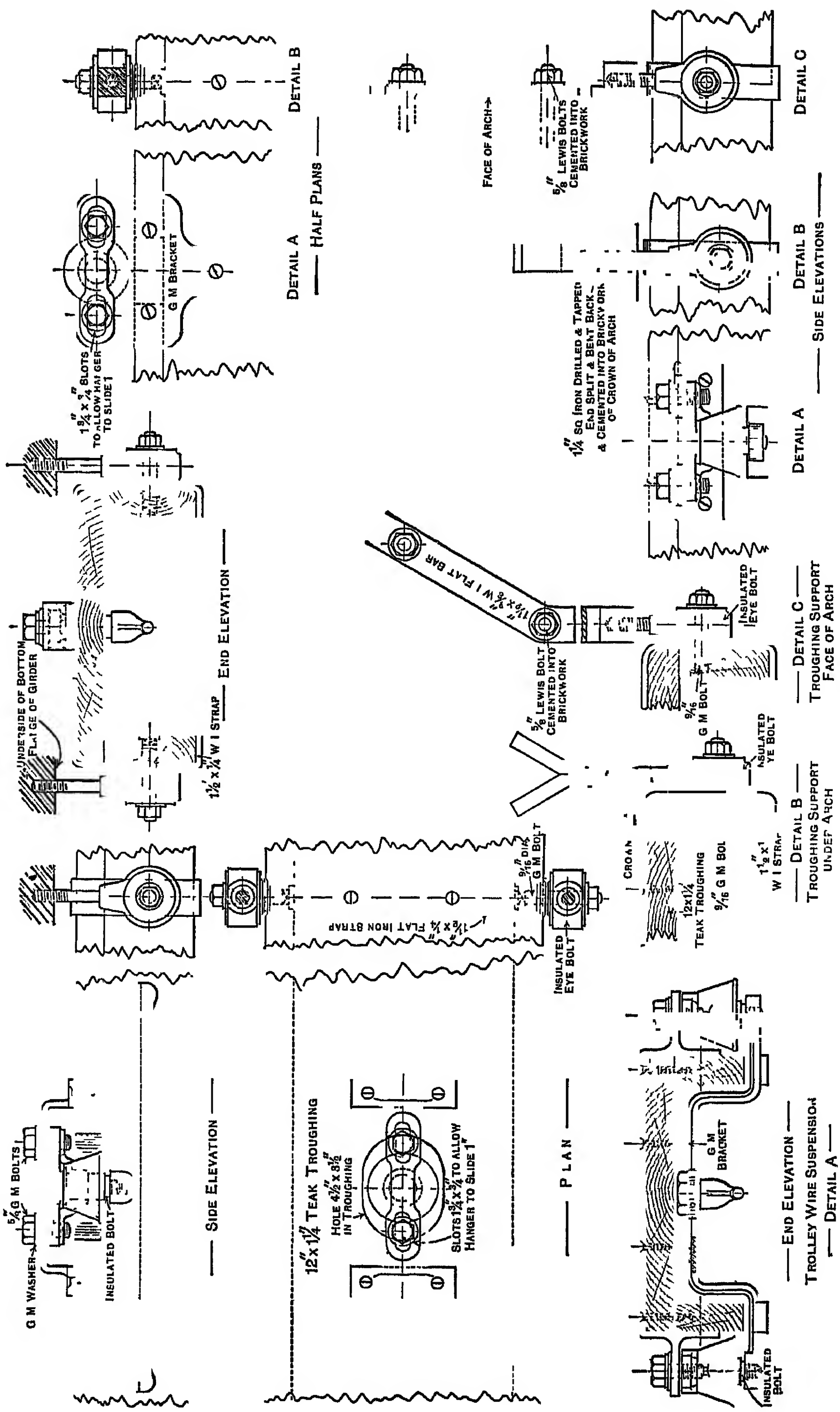


Fig 995 —Details of Troughing, Insulators, and Hangers under Girder and Brick-Arch Bridges

tension on the trolley wire will be even throughout its length, and this buckling will be avoided. Details of this arrangement are shown, fig. 995, which were designed to take up the minimum amount of head-room. It will be noticed that the arrangement shown gives a treble insulation at this point This is not essential from the tramway stand-point, but the elect.. advisers of the railway companies, whose approval is generally necessary . the attachment of wires to a bridge, are usually somewhat exacting in the.. requirements with regard to insulation, for fear of interference with the railway signals. The designs shown should meet all reasonable requirements

Where the swivel-headed trolley is used it is advisable to place the trolley wires at least 3 feet outside the edge of the car, as in this position it is impossible for passengers on the roof to touch them, and several extra inches of head-room are thus secured

Another form of bridge which sometimes causes difficulty is the old-fashioned stone arch carrying the road over a canal or small stream These bridges are frequently made with a very high crown and sharp approaches, and, as it is usually impossible to place a pole on the crown of the bridge, they seriously reduce the height of the trolley above the car They can be dealt with by placing four poles, from 2 to 3 feet longer than the standard pole, as close as they can be set to the crown of the arch Pull-offs can be run from the top of these poles to the trolley wire at the centre of the bridge, and the trolley lifted up to practically the standard height

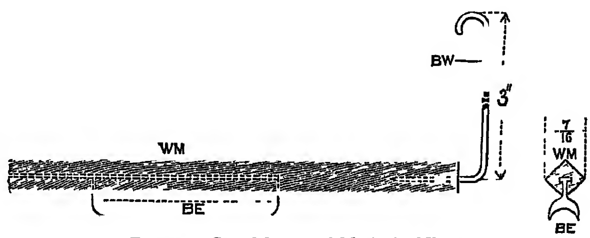


Fig 996 —Guard Strip and Method of Fitting

Guard-Wires —Whenever the trolley wire is crossed by telephone or telegraph wires, the Board of Trade in England, and the governments of the several European countries, require that devices shall be used to prevent a fallen telephone or telegraph wire coming in contact with a trolley wire Two arrangements are in common use, the guard-strip as shown, fig 996, which consists of a light strip of wood of approximately triangular section, held to the top of the trolley wire by small clips of sheet-copper, and provided with short wire-guards at the insulators, the other by stretching wires about 18 inches above and parallel to the trolley wire. The different arrangements of guard-wires for single and double line, at various distances apart, are as described in the Board of Trade regulations.

It was formerly the practice to insulate these guard-wires carefully, and is still so in some of the European countries, and a whole series of insulators and fittings have been designed for this purpose, but the English regulations now provide for these guard-wires being very carefully earthed at frequent intervals. It is therefore only necessary to secure the guard-wire proper to the span-wire by the small clips shown, fig. 997, or to the standards provided on the bracket arms (figs. 998 and 934).

The theory is, that the falling wire will first come in contact with the earthed guard-wire, and then, if, from any coiling action or from being caught by a passing vehicle, it should come in contact with the trolley wire, an absolute short circuit will be formed which will open the circuit-breakers in the generating station and cut the current off the trolley wire. The guard-strip only aims at keeping the fallen wire out of contact with a trolley

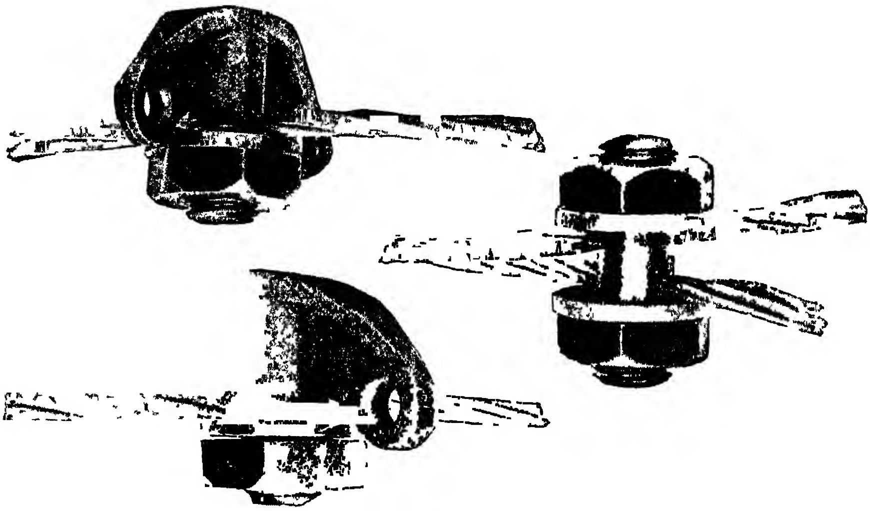


Fig 997 —Guard-Wire Clips

wire It has very little mechanical strength, and is little or no protection against the tendency of the trolley wire to coil Seven-stranded steel cable of 16 gauge is now required for the purpose of guard-wires

Whether guard-wires or guard-strips are used, their additional weight and strain must be taken into consideration in determining the size and location of poles. Where wires cross curves or junctions it is practically impossible to erect efficient protective devices, and in such cases arrangement should be made with the owners of these wires to deflect them at these points.

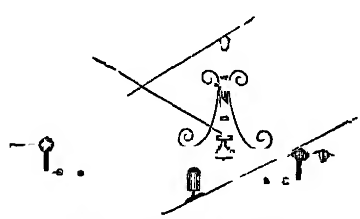


Fig 998 —Guard Wire Standard

The attitude of the authorities towards tramways on the guard-wire question is somewhat unfair They compel the tramway to afford protection against defective workmanship or maintenance on the part of the owners of the telephone and telegraph wires, not only in regard to wires in position before the tramways were built, but any additional wires that may be erected.

Guard-wires are very unsightly, a considerable expense, and a source of danger to the tramway, as, in event of the trolley leaving the wire, it is very liable to get caught in the guard-wires and pull them down. The actual amount of protection afforded by the guard-wires is in most instances

very slight. This refers particularly to long spans, and spans crossing the trolley lines at a sharp angle

Co-operation between the respective owners of the wires would enable a much more efficient protection to be given, and much less disfigurement. But this co-operation is difficult to arrive at, as the owners of the telephone and telegraph wires usually adopt an impossible attitude, saying in effect:—The Board of Trade regulations throw the whole responsibility on you, why should we trouble ourselves in the matter?

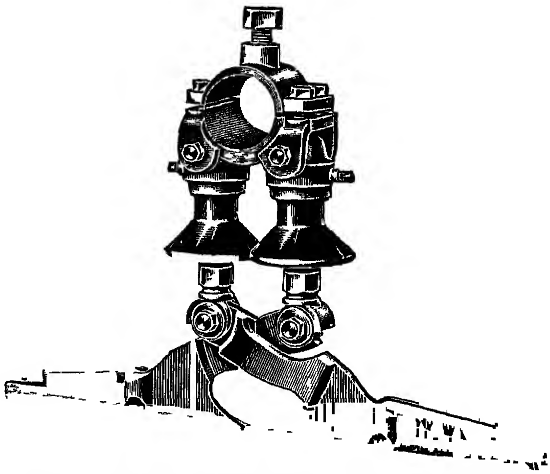


Fig 999 —Patent Ear for Cutting out Fallen Section of Trolley Wire

The best protection would probably be afforded by making the spans of the wires crossing the trolley lines as short as possible, and at right angles to the trolley wire This span should be shackled off at each end to prevent the wire "running through", and should be insulated The length of guard-wire needed could then be reduced to a minimum, if not altogether omitted. These crossing points should be made as few as possible, and the practice of running single wires across the trolley wire at odd intervals and awkward angles be prohibited The expense of this would have to be borne by the tramway in regard to wires already in position, but they should not be compelled to pay for the protection of wires erected at a later date.

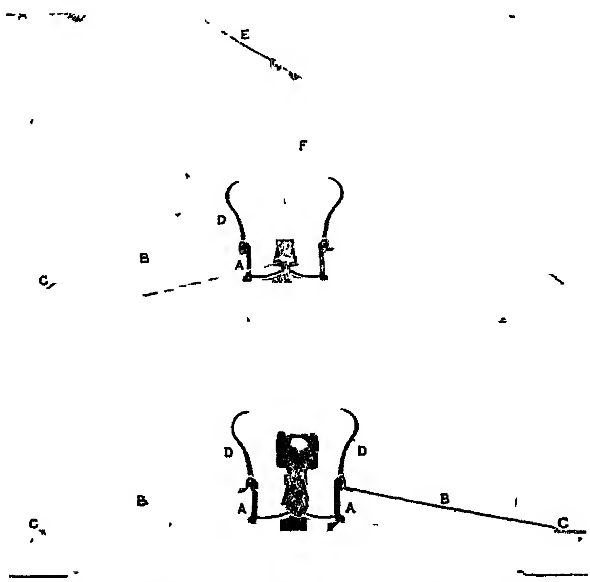


Fig 1000 —Device for Earthing Fallen Section of Trolley Wire

Safety Devices.—A number of safety devices have been brought out to guard against accidents resulting from fallen wires, caused either by the breaking of the trolley wire, or the falling of telephone or telegraph wires.

The former are usually devices which are held in place by the tension on the trolley wire. Should this be released, the circuit is either opened (fig. 999), or the trolley wire completely released and allowed to fall into the street, or earthed to form a short circuit (fig 1000). The latter are various arrangements whereby the fallen wire, coming in contact with the trolley wire and guard-wire, acts as an automatic circuit-breaker, or similar devices cutting the current off from that section of the line.

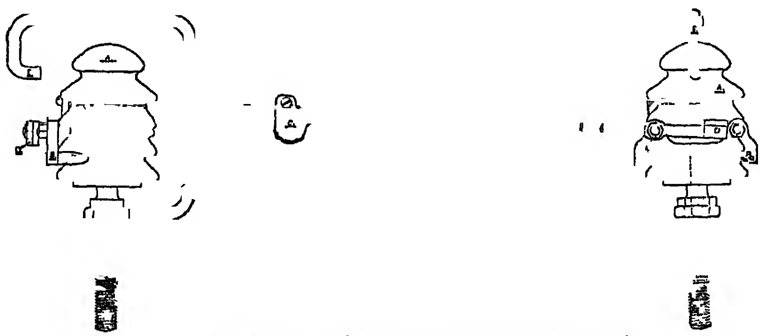


Fig 1001 —Device for Earthing Fallen Telephone Wire

Another device, shown in fig. 1001, is attached to the telephone wire If the wire breaks, it is immediately earthed, and if the telephone wire touches the trolley wire, a short circuit is formed which opens the circuit-breaker in the generating station.

None of the devices thus far produced seem of a very practical nature, and the extra complications which they introduce considerably outweigh their value as safety devices, and most of them do not comply with the regulations of the Board of Trade

APPENDIX

BOARD OF TRADE REGULATIONS CONCERNING GUARD-WIRES ON ELECTRIC TRAMWAYS (MAY, 1902)

If and whenever telegraph or telephone wires, unprotected with a permanent insulating covering, cross above, or are liable to fall upon, or to be blown on to, the electric conductors of the tramways, efficient guard-wires shall be erected and maintained at all such places

EXPLANATORY MEMORANDUM

NOTE.—The expression "telegraph wire" includes all telegraph and telephone wires

For the purpose of this memorandum, telegraph wires are divided into two classes, namely —

(*a*) Wires weighing less than 100 lbs per mile.

(*b*) Wires weighing 100 lbs. or more per mile

Each guard-wire must be well earthed at one point at least, and at intervals of not more than five spans The resistance to earth must be such that a short circuit between a guard-wire and a trolley wire will open the circuit-breaker.

The earth connection should be made by connecting the support to the rails by means of a copper bond. When first erected, the resistance to earth of the guard-wires should be tested, and periodical tests should be made to prove that the earth connection is efficient.

Guard-wires should be, in general, of galvanized steel, but in manufacturing districts in which such wires are liable to corrosion bronze or hard-drawn copper wires should be used

The gauge of the guard-wire must be such that it will carry, without fusing, a current 50 per cent greater than that required to open the circuit-breaker, and the

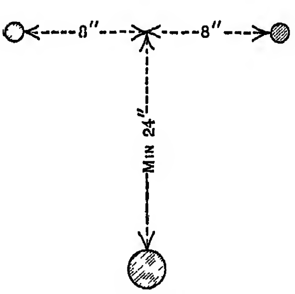


Fig 1002

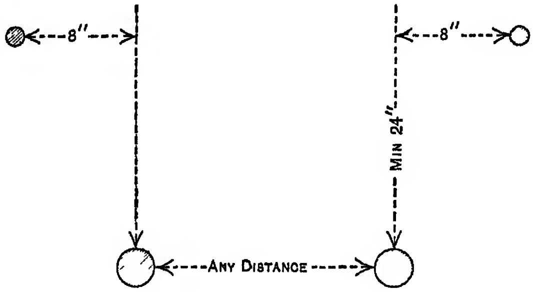


Fig 1003

guard-wire must be maintained in such a manner that it will at all times meet these requirements

The supports for the guard-wires should be rigid and of sufficient strength for their purpose, and at each support each guard-wire must be securely bound in or terminated

The rise of the trolley boom should be so limited that if the trolley leaves the wire it will not foul the guard-wires.

Telegraph Wires crossing Trolley Wires

Class (a).—Wires weighing less than 100 *lbs per Mile*

The guard-wires may be of the cradle or hammock type, attached to the arms of telegraph poles It is necessary that the spans should be short, and if required an additional pole or poles should be set

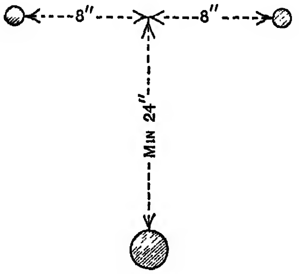


Fig 1004

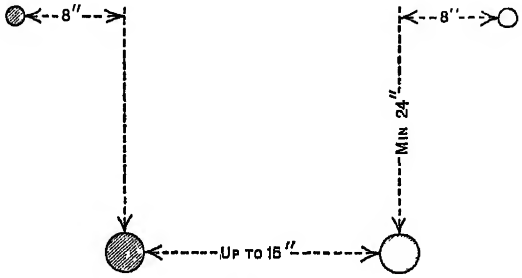


Fig 1005

(1) Where there is one trolley wire, two guard-wires should be erected (fig. 1002).

(2) Where there are two trolley wires any distance apart, two guard-wires should be erected (fig. 1003)

(3) In special cases, at junctions or curves, where parallel guard-wiring would be complicated, two guard-wires may be so erected that a falling wire must fall on them before it can fall on the trolley wire

Class (b)—Wires weighing 100 lbs. or more per Mile

(4) Where there is only one trolley wire, two guard-wires should be erected (fig 1004).

(5) Where there are two trolley wires not more than 15 inches apart, two guard-wires should be erected (fig 1005)

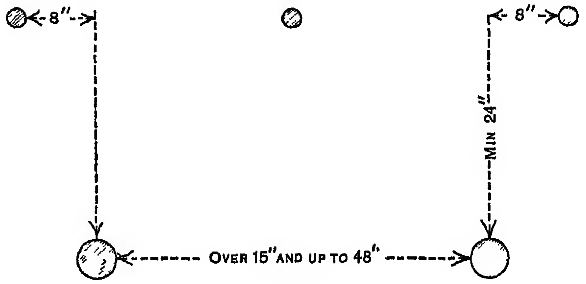


Fig 1006

(6) Where there are two trolley wires and the distance between them exceeds 15 inches, but does not exceed 48 inches, three guard-wires should be erected (fig 1006)

(7) Where the distance between the two trolley wires exceeds 48 inches, each trolley wire should be separately guarded (fig 1007)

(8) It is desirable, where possible, to divert telegraph wires from above trolley junctions and trolley-wire crossings, and undertakers should endeavour to make arrangements to that effect with the owners of telegraph wires

Telegraph Wires parallel to Trolley Wires

Classes (a) and (b)

(9) Where telegraph wires not crossing a trolley wire are liable to fall upon or to be blown on to a trolley wire, a guard-wire should be so erected that a falling wire must fall on the guard-wire before it can fall on the trolley wire

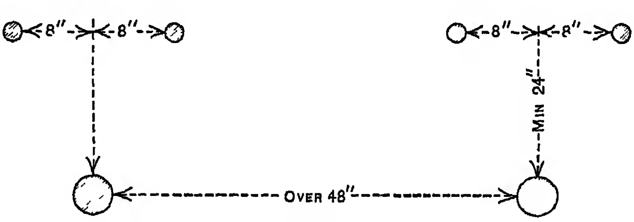


Fig 1007

(10) When guard-wires are attached to other supports than the trolley poles they must be connected with the rails at one point at least

(11) When it is possible that a telegraph wire may fall on an arm or a stay, or a span-wire, and so slide down on to a trolley wire, guard-hooks should be provided

General

Minimum guarding requirements for Classes (a) and (b) are provided for in this memorandum, but in exceptional cases, such as in very exposed positions, or for unusually heavy telegraph wires, special precautions should be taken.

4. Tramway Feeders

CHAPTER I

ARRANGEMENT OF FEEDERS

Location of Generating Station.—The design of a system of feeders for a tramway is a matter of some difficulty, owing to the fact that both the amount of power required and the distance through which it is to be transmitted are continually varying between wide limits. This renders a feeder system, which will maintain the potential for the entire system within the narrow limits required by a net-work of lighting mains, a practical impossibility. Fortunately, however, this extreme closeness of the regulation of the potential is not required. A variation of as much as 20 per cent may be allowed without serious inconvenience, and this may, in exceptional circumstances, be increased to 25 per cent.

It becomes, therefore, more a matter of judgment based upon the close study of the local conditions, of the volume of traffic to be handled, of its distribution and fluctuations, and of the possible or probable extensions of the system, than a matter of mathematical calculation.

It is necessary to determine with a considerable degree of accuracy the size and weight of the cars to be used, and the frequency of service that is to be maintained upon each route. This will form a basis upon which to work.

Next must be determined the location and severity of the gradients and the sharpness of the curves, bearing in mind that for the determination in the average power required, the gradients, unless of exceptional severity or length, are nearly negligible, because the cars in descending the gradients take no current at all, and in ascending the motors are working at a very much higher degree of efficiency than on the level. The average amount of power required is not appreciably increased, but the maximum power required may be, and if so must be provided for in the feeder system. With curves it is, however, different, as they take an equal amount of current in both directions, and this materially increases the average amount of power required.

Now must be considered the possibility of intermittent or recurrent demands for power, their extent, duration, frequency, and location. By these are meant the concentration of traffic caused by a football match or similar attraction, the extra heavy traffic occurring on certain days of the week or month, the increase of traffic usually experienced in the morning

and evening, and the congestion of traffic liable to be caused by the disarrangement of schedule.

So long as the cars run with a reasonable degree of closeness to their predetermined schedule, the load on any particular section will be fairly evenly distributed, and if the line has no severe gradients or sharp curves, may be considered, for the purpose of determining the average load on that section, and the location of the generating station, as concentrated at the centre This may be considered the centre of gravity of that section This centre of gravity will be shifted one way or the other by the curves and gradients, and any other causes which call for an abnormal amount of power at specific points Possible extensions should also be considered, and the degree to which they may be allowed to influence the location of the generating station will depend upon the probability of their being carried out

The next step will be to determine the best location for the generating station A convenient method of doing so is as follows —The above-mentioned points having been determined as accurately as the data available will permit, a diagram of the tramways should be prepared, which will show the various portions of the system in their correct relative positions, and to a convenient scale; a large one is not necessary, 6 inches to the mile being quite sufficient.

In the diagram in fig 1008 we will assume that there is a service of cars between A and G, to maintain which requires twelve cars If the route was level and without sharp curves, these twelve cars might be considered as concentrated at I, the centre point between A and G However, at K we have curves and gradients which absorb the power equivalent to three cars This fact will move the centre of gravity from I towards K. The distance from I to K is say 1500 feet We now have the equivalent of a simple lever 1500 feet in length, with twelve units on one end and three on the other The fulcrum or centre of gravity will therefore be 300 feet from I, *i e* at L, and has a value of 12 + 3 = 15. The other lines are dealt with on the same basis, and we will assume that the line B H has a value of six cars concentrated at M, that D N has a value of seven concentrated at P, that C E has a value of four concentrated at O, that J F has a value of five concentrated at Q

The centre of gravity of each route having now been determined, the next step is to ascertain the centre of gravity of the entire system. Draw lines from Q 5 to L 15 The centre of gravity of these two points will be found on this line at R, a point one-fourth the distance between them from L, and will have a value of 20 The centre of gravity between M 6 and P 7 will be found at S, and will have a value of 13 The centre of gravity between S 13 and O 4 will be found at T, and will have a value of 17 The centre of gravity between R and T will be found at V, and will have a value of 37 This is the centre of gravity of the entire system, and the point from which the most economical distribution of power can be made as regards feeders, and, other conditions being favourable, the power station should be located here It does not matter in what order we make these combinations, for a system can have but one centre of gravity.

Any material departure from this point for the generating station causes the expense of the feeders to mount up with alarming rapidity. It is not, however, always possible to locate the generating station at the centre of gravity, owing frequently to the heavy cost of land, the absence of water for condensing purposes, or to difficulty in obtaining fuel In considering the location for the power station it will be necessary to figure out the cost of the feeder system on the assumption that the generating station is to be located in its theoretically correct position, at the centre of gravity, as this will form a criterion that will enable the designer to determine to what

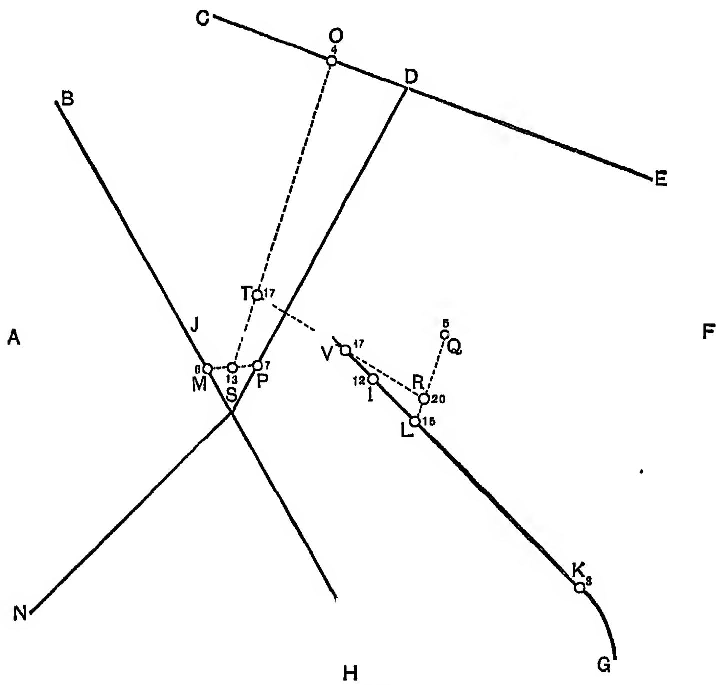


Fig 1008

extent a change in the location of the station will increase the cost of feeders, against which must be balanced the advantages of the proposed site as to cheap land, water, and fuel.

Sectional Arrangement of Feeders.—The next point to be considered is the sectional arrangement of the feeder system, and for this purpose the trolley wire must be considered as part of the feeder system

It has now become standard practice to divide the trolley wire into a number of sections. These sections will have a greater or less length according to circumstances. In England the lengths of these sections are arbitrarily fixed by the Board of Trade at a maximum of $\frac{1}{2}$ mile, but in countries where this distance is not fixed the lengths of the sections will be governed chiefly by traffic considerations, and to some extent by the geographical relations of the various routes.

There are two different ways of feeding the various sections of the

trolley wires. Both have their advantages and disadvantages One as in fig. 1009, where the sections of trolley wire are fed at both ends, and the other as in fig 1010, where they are fed at one point only

The first is the most economical as regards copper, as it makes full use of the trolley wire, but it makes the switching arrangements very much more complicated and expensive. It has the advantage that, in the event of a fault in any section of the underground cable or trolley wire, the section of cable or trolley wire can be easily cut out by means of switches

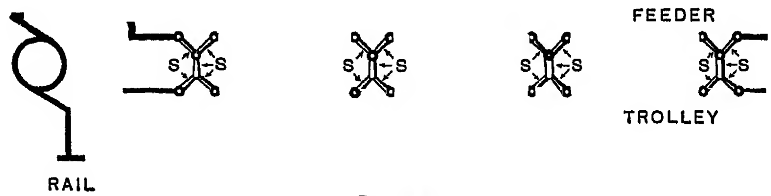


Fig 1009

S S (fig 1009), and the route beyond that point worked through the remaining conductor.

The second arrangement makes use of the cross-section of the trolley only between the feeding-in point and the car, but has the advantage of greater simplicity.

The theory of the Board of Trade regulations, in regard to sectional trolley wire, is that in event of an accident and the wire dropping into the street the current should be cut off with a minimum of delay Traffic considerations demand that this shall disable as small a portion of the system as possible. This can be best accomplished by so designing the

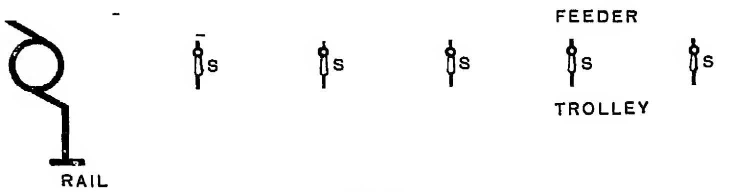


Fig 1010

feeder system that each section of trolley wire is normally fed from one point only, but is capable of being fed from two or more points, and preferably from two or more feeders.

When it becomes necessary to cut out from a single point a section of trolley wire fed on the first system (fig. 1009), the feeder has to be cut out as well, and this renders dead all the route beyond that point, and also requires the manipulation of several switches to accomplish it Thus a single fault in either the overhead line or cables must disable an entire route, perhaps several miles in length, and which operates a considerable number of cars that cannot be started again until the operator has gone to the other end of the disabled section, opened the switches necessary to cut out the faulty section, come back to the first box, and closed the main feeder or trolley-wire switch as the case may be. The expense of making

this arrangement is also very considerable, as the main feeders have to be brought into the pillar-boxes and provided with switches. These switches are a source of leakage and also a trouble and expense to maintain

In the second arrangement (fig 1010) the cutting out of a section of trolley wire does not affect the service on the rest of the route in the least, and requires the movement of but a single switch. But a fault in the cable is rather more troublesome than with the first arrangement, as the entire feeder must be cut out and jumpers placed around the section insulators. A precaution against this is usually taken by dividing the feeder in two or more sections of convenient length. If the cables are properly laid and carefully jointed, a fault in the feeders themselves should be rare

The greatest number of faults occur in the feeding-in and in the overhead wires. The feeding-in wires particularly are a source of trouble, as, owing to the limited space inside of the pole, they are very apt to be damaged in the drawing in, and the vibrations of the pole are also apt to wear the cables through in places For this reason the writer believes it

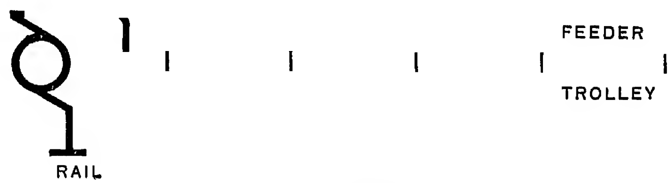


Fig 1011

the best policy to restrict the feeding-in wires to as small a number as possible

In the second arrangement (fig 1010) the best economy of copper will usually be secured by feeding the end of the section nearest the station, as in fig 1011 This can be done without difficulty in most cases, as the trolley wire is usually sufficient in cross-section to feed the cars upon it Feeding from the middle gives a somewhat better distribution of potential at the car, and also reduces the time necessary to cut out a disabled section of trolley wire

Two trolley wires, whether single or double track is used, have now become practically standard The question as to whether the trolley wires are to be connected together or insulated from each other will require consideration. Connecting them in multiple makes a more efficient use of the copper in the trolley wire, but renders the route liable to disablement from a single fault. If the trolley wires are kept insulated from each other, and one trolley wire becomes earthed, it is usually possible to work the service with a lessened degree of efficiency on the single wire. But the separate trolley wires necessitate double the number of switches and feeding-in wires, which increases the liability to faults

If the section contains severe gradients it is advisable to arrange the feeding-in points as near the gradient as possible, particularly if the one-point method of feeding is adopted.

If the method of feeding from both ends is considered the most desirable, with a little care in arranging the lengths of the sections it is usually

possible to feed close to the gradients. If the trolley wires are connected in multiple this matter becomes of somewhat less importance.

Where branches and junctions occur, both trolley wires should be considered as one section, which section should be made as short as possible, as it is impracticable to insulate the trolley wires from each other at these points.

Distribution of Potential.—Feeder systems should be so designed as to secure as nearly as possible an even distribution of potential at all points. Owing to the rapid and violent fluctuations of the load and the

Fig 1012

rapid shifting of its position, this can only be accomplished to an approximate degree It must be entirely automatic, as the changes are altogether too sudden to admit of anything like hand regulation at the station The generators should be overcompounded, at least to the extent of the average drop This overcompounding is usually made 10 per cent, except in special cases where storage batteries are used in connection with the generators

The arrangements of feeders shown in figs. 1009 and 1010 do not in any way assist in obtaining an even distribution of potential, as they form with the trolley wire practically continuous conductors.

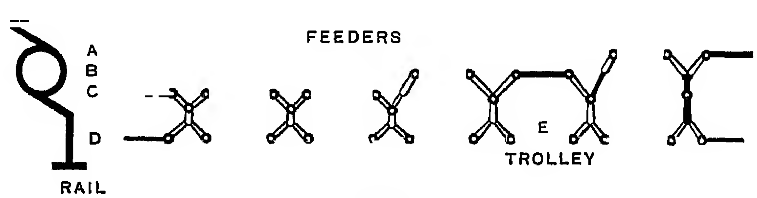


Fig. 1013

By the arrangements shown in 1012 an approximately even distribution of potential can be obtained, the evenness of distribution being limited by the number of separate feeders which it is practicable to run. This arrangement is simple and answers extremely well for the average load, but in any system liable to a congestion of traffic at a point some distance from the generating station, or of having the load at any one point occasionally greatly exceed the normal, the arrangement shown in fig 1013 is more suitable, although very much more complicated, and in order to comply with the Board of Trade regulations requires a very large number of switches. In the event of an excessive load at E the point would be fed by feeders B and C, and trolley wire D in multiple, and by feeder A from the other end of the section. But for most cases

the simpler arrangement of fig. 1012 would be amply sufficient, there is much less liability of the employees making the wrong connections

In an extended system it might even be necessary to make use of several or all of the above arrangements, according to the service required. That shown in fig 1013 might be used on the important and busy routes, where the cars are liable to be bunched at one point. That shown in fig 1012 could be used on routes where the load was reasonably steady, and the arrangements of figs. 1009 and 1010 could be on the lines where the traffic is light and of not much importance.

In most cases it is not necessary to run the feeders beyond the last section insulator, leaving cars on the last half-mile to be supplied from the trolley only. In a great number of cases the last mile, and occasionally a mile and a half or two miles, may be worked from the trolley wires alone, particularly if the wires are connected in multiple.

CHAPTER II

ECONOMICAL LOSS IN FEEDERS

The percentage of loss allowable in the feeders should now be determined Kelvin's law in regard to economy in lighting conductors, that the cost of the power lost in the conductors should equal the interest on their cost, is equally correct for tramway feeders, but is more difficult of application, as the factors governing the loss are not so easily ascertainable Also, the necessity for providing sufficient feeders to prevent the potential at maximum momentary load from falling below the working limit renders the application of the law in many instances impossible

Under normal conditions the most economical average drop will usually be found somewhere between 5 and 7½ per cent, and should never exceed 10 per cent This is, of course, inclusive of the drop in the return circuit, but as far as English practice is concerned this is usually a negligible quantity, seldom exceeding 3 or 4 volts The maximum drop allowable should not exceed 25 per cent, assuming the generators to be overcompounded 10 per cent, thus giving 550 volts, as this reduces the working voltage to about 415, below which point the motors will not give out their full power nor work up to their proper speed. These difficulties seriously interfere with the efficiency of the service. This amount of drop represents the maximum allowable, and it should never equal this except at momentary maximum loads In fact it is much more satisfactory to keep the maximum drop to be expected under normal conditions down to 10 per cent, because the full value of overcompounding of the generators is not always available, as it is dependent upon the entire load on the station and not on any one feeder.

As reliability and regularity of operation are the fundamental principles of tramway service, an average drop of 5 per cent should not usually

be exceeded, especially if the tramway is situated in a district which is liable to snow-storms, for a sharp fall of snow will frequently, in the course of an hour's time, create a demand for at least double the amount of power usually required

If the system is designed for a 10-per-cent average drop, the snow-storm will at once increase this to 20 per cent, which will render many portions of the line inoperative, by reducing the potential below that required to get the full power from the motors which would be needed under these circumstances, and a curtailment of the service would be the only remedy.

The average amount of current required per car will vary with the weight of the car and the gradient With a grooved rail, as is usual in English and Continental practice, about 1½ ampere per ton will be required, but with a "T" or step rail 1¼ ampere per ton will be sufficient In both cases 1¼ ampere per ton should be added for each 1 per cent of gradient (that is, for each foot rise in the hundred) This will work out in most conditions to an average of about 15 amperes for the ordinary four-wheeled car, and about 20 or 25 amperes for a bogie car.

On very large roads the maximum current required will often not exceed the average by 25 per cent, but on small tramways, operating, say, 15 cars, it will frequently run up to three or four times the average By a recent rule of the Board of Trade the amount of current carried by any one feeder must not exceed 300 amperes This regulation makes it practically necessary to consider a large tramway as a number of small individual tramways, each having a station capacity of 300 amperes This materially simplifies the feeder calculations, but on a tramway operating 100 or more cars it does not improve the economies, as it is not often possible to make the various individual feeders help each other out in times of overload without excessively complicated switching gear

The number of cars of the ordinary four-wheeled type which can be operated with 300 amperes as the maximum current available will be from 10 to 18, according to the character of the road and traffic About 15 may be taken as a fair average The above limit of 300 amperes presents no special difficulty in a moderate-sized tramway of, say, 100 to 150 cars, as it is distinctly advisable to so arrange the feeder system that the failure of one cable will not even momentarily throw more than 10 or 15 per cent of the cars out of service

The sectional area of the feeder to convey any current with a given drop can be determined from the following formula·—$A = \frac{KCL}{E}$, in which A equals the area of conductor in square inches, C current in amperes, E drop in volts, L length of conductor in feet or other convenient unit, K the resistance in ohms of a conductor 1 square inch in section and of the length of one unit of L.

The drop in volts for a known current distance and cross-section can be determined by the following formula —$E = \frac{KCL}{A}$. In practice, however, it is much more convenient to work from one of the numerous

tables or charts which are available for this purpose. A very good one is issued by W. T. Glover & Co.

In determining the cross-section of the various feeders required, the cross-section of the trolley wire is first fixed This is governed rather more by mechanical than by electrical considerations. Unless the entire current can be carried by the trolley wire there is no advantage, from an electrical stand-point, in increasing the size of the trolley wire beyond the

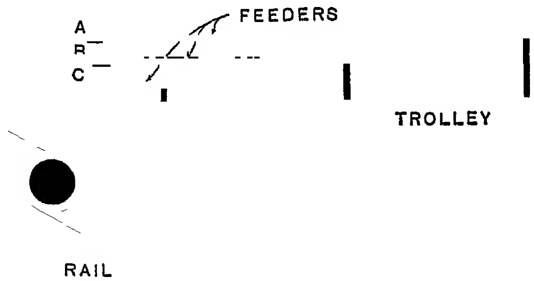


Fig 1014

minimum required for mechanical strength and wearing capacity, as the cost for the insulators and supports for the heavier sizes of trolley wire are greater than the cost of increasing the sectional area of the feeder to the same extent

The section of the trolley wire being fixed, and the total permissible average drop being selected, the amount of drop in the trolley wire itself is first ascertained If the arrangement is as shown in fig 1014, the feeders A B and C are simply proportioned to absorb the rest of the drop If, however, the arrangement is as in fig 1015, which would represent a

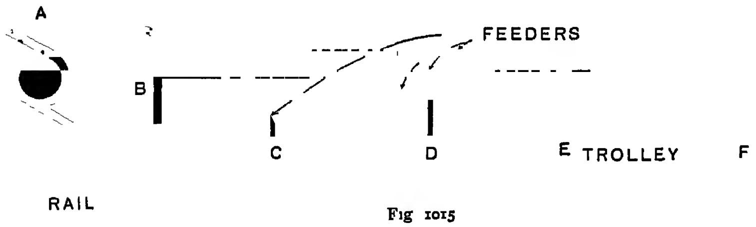


Fig 1015

case where the generating station was some distance from the centre of distribution, after ascertaining the drop in the trolley wire, the balance of the drop is apportioned between A B and B C, B D, B E, and B F, the feeders B C to B F being so proportioned that the drop in each shall be about equal. As a general rule it will be better to arrange for the greater part of the drop to take place between A and B As the feeders B C to B F vary very considerably in length, an approximately equal fall of potential in each may cause so much energy to be wasted in B C as to cause dangerous heating in this length

If power is cheap, and it has been decided to allow for a very considerable drop, it will be best to put the heaviest drop in feeders B C to B F,

as their combined emissivity will be considerably greater than that of the feeder A B.

The arrangement shown in fig 1016 is much more complicated, and the exact determination of the drop in the various sections would involve a tedious amount of calculation For tramway purposes it would be sufficient to consider it as separated at D and E; the sections A^1 and A^2

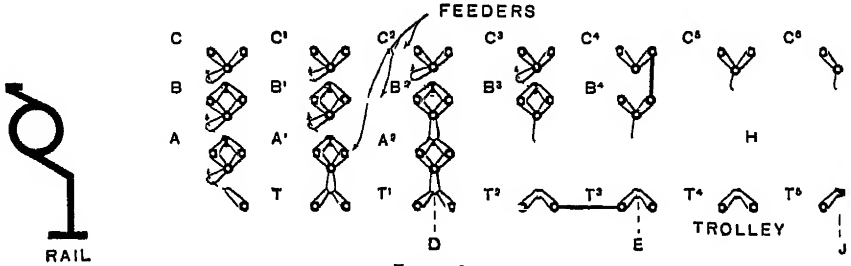


Fig 1016

and T and T^1 would be regarded as a single conductor, with half the sum of T and T^1 concentrated at D. The predetermined drop would then be suitably divided between A and these four sections regarded as one conductor. The sections terminating at E would then be dealt with in a similar manner, and the last section on the basis that half the load of T^4 and T^5 was concentrated at J.

The net-work of lines shown in fig 1017 is rarely met with in English practice, as, owing to the Board of Trade regulations as to sectional trolley wires and the limit of current in any one feeder, it is not generally possible to take advantage of the economies afforded by a net-work. The exact determination of the several amounts of current, and hence the drop in the various members of the net-work, is a matter of formidable calculation, and in tramway work the even distribution of potential is not of sufficient importance to warrant this Two main conditions only need be fulfilled first, that each member of the net is of sufficient section to carry its individual current without exceeding its proportion of the predetermined drop; second, that the sum of the currents required by the several members must be carried at certain points (which to a certain extent can be predetermined) without exceeding the assumed maximum drop.

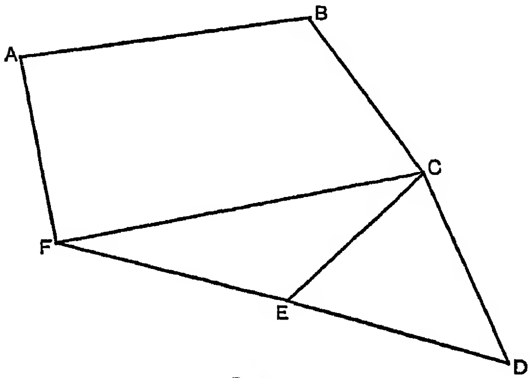


Fig 1017

It is usually convenient to first determine the cross-section required for each member of the net as an isolated line, which can usually be simplified by considering the main routes of traffic, such as A B C D. as a

single conductor carrying the loads A B, B C, and C D, treating A F E D in a similar manner, F C and E C being considered separately. This arrangement of conductors will form a base to which must be added the amount of conductors required for the concentrated load, and the exact method of strengthening the net to the best advantage is a matter of discrimination.

If the traffic is liable to be congested at D and E, A F and E should be strengthened. If C and B are the threatened points, A B C should be increased. From the foregoing it will be gathered that it is always possible to split up a net-work of tramways into a combination of lineal systems and branches, the loads upon which will fluctuate through such wide limits that it will render the exact determination of the drop in the various members of little importance.

The above calculations for average drop will form a base for the next step, which is the determination of the maximum drop. The most advantageous section of feeders for average drop having been determined, it will be necessary to go carefully over the entire system, and ascertain at what points congestion of traffic is liable to occur and how great this congestion may be. The various members of the feeder system are then necessarily strengthened to meet this demand, or separate feeders are run to the threatened points, whichever may seem most desirable.

CHAPTER III

SPECIAL METHODS OF TRANSMISSION

Boosters.—A booster is in effect a small generator in series with a feeder (fig 1018), and used to increase the potential of that particular feeder. It has the same general effect in regard to feeders as over-compounding of the main generators, but can be applied to any feeder

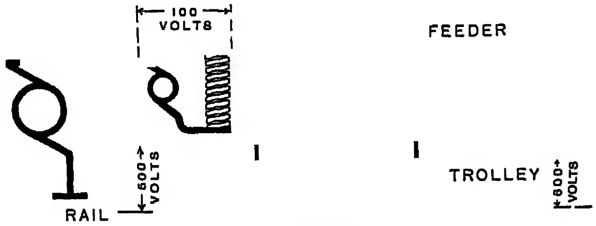


Fig 1018

or group of feeders without affecting the potential of the balance of the system, and any feeder can be thus overcompounded to meet its special requirements.

The booster can be driven by any convenient form of motive power; this is usually accomplished by an electric motor, and it need only be of sufficient power to furnish the increased voltage. For instance, to

raise the potential on any feeder carrying, say, 100 amperes from 550 to 650 volts, or an increase of 100, would require a booster of 10 kilowatts capacity, and a motor of sufficient size to develop this power.

The booster forms a very convenient and satisfactory method of dealing with concentrated loads at some distance from the generating station, when these loads are of short duration and infrequent occurrence. But it should never be used for continuous loads, for if the load is reasonably constant it will be much better economy to put in sufficient copper to keep the potential within the proper limit. The loss of power occasioned by the booster itself, coupled with the very heavy drop which a feeder will certainly have to warrant the use of a booster at all, mounts up very rapidly, as will be shown from the following example.

Suppose it becomes necessary to transmit 310 amperes a distance of 4 miles from the generating station, and it is decided to boost this current to the extent of 100 volts, and that the potential at the end of 4 miles is to be 440 volts. It is assumed that the full value of the overcompounding of the generator is utilized, giving 550 + 100 = 650 volts at the station. The number of kilowatts furnished by the booster will be 31, and the combined efficiency of booster and motor will vary between 65 and 85 per cent, according to the size of the booster. In this instance we will assume 80 per cent. There will therefore be lost in the booster 7.75 kilowatts. The potential in the line will fall from 650 to 440, or 210 volts, which, with 310 amperes flowing, will absorb 65.1 kilowatts. The total loss will therefore be 72.85 kilowatts. Assuming this loss to continue for an average of 15 hours per day, which is about usual for tramway practice, we have a total loss of 398,853 kilowatt-hours per annum. Assuming this to cost 1*d* per kilowatt-hour, which is a fair price for power as generated by a tramway station of average size, the total value of the loss in feeder and booster will be £1661 per annum. Plus the upkeep of the booster and motor, will bring the total cost up to at least £1670 per annum.

The size of feeder necessary to transmit 310 amperes for 4 miles with a loss of 210 volts will be .25 inch. The cost of this cable, with paper insulation, lead-covered, exclusive of laying, would be about £1896. The cost of the booster and motor, of say 31 kilowatts each, would be (at £5 per kilowatt) £310, making a total of £2206 of capital, upon which the interest at 5 per cent would be £110, or a total annual cost of £1780. To transmit this same amount of current, and maintain 440 volts at the end of the feeder without the aid of the booster, and assuming that the full extent of the 10-per-cent overcompounding is available, would require a feeder with a sectional area of .5 square inch, costing, with the same grade of cable as above, £3440, the interest upon which, at 5 per cent, is £172. The loss in this feeder of 105 volts while transmitting 310 amperes would be at the rate of 32.5 kilowatts per hour, and figured for the same number of hours would come to £741 in the course of a year, or a total of £913.

From this it will be seen that, although the booster system is cheaper in first cost, it is much more expensive to operate if the load is con-

stant; but if it is necessary to provide for a maximum load of about five times the average the booster will be found useful

It should be borne in mind that the cost of laying the smaller feeder will not differ appreciably from that of the larger, and that the cost of the cables do not increase in the direct ratio to their sectional area

The chart (fig. 1019) shows the ratio of cost to area for cable of the usual paper-insulated lead-covered type

As the cost of laying frequently exceeds the cost of the feeders themselves, especially with the smaller sizes, it will be seen that the greatest economy in first cost will be attained by the use of short feeders of large sectional area, allowing a large proportion of the allowable drop in the trolley wire. This arrangement gives a very variable

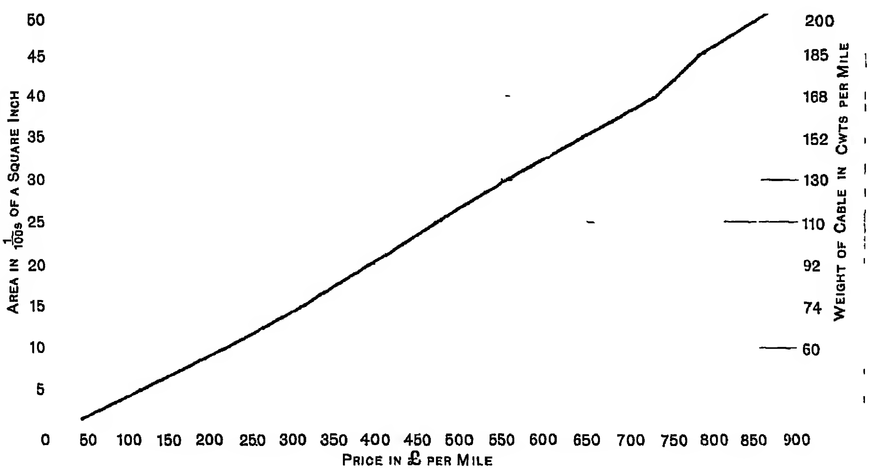


Fig. 1019

potential on the line, the chief disadvantage of which is the violent fluctuations in the light given by the lamps in the car

To what extent it is advisable to increase the first cost in order to secure an even illumination must be decided by local circumstances The tendency seems to be to obtain good light at any cost, and although steady lighting in a car has a distinct commercial value in popularizing the tramway, from an economic stand-point it is, in many cases, not worth the additional cost.

Negative Boosters and Track Feeders.—Negative boosters are frequently used in connection with the track feeders to overcome the drop in the return circuit and keep this within the Board of Trade limits.

It is only under exceptional circumstances that track feeders are commercially justifiable, unless used in connection with the negative boosters above referred to, as the excessive cross-section of copper that would be required to afford any appreciable relief to the return circuit would render their cost prohibitive. But when the geographical arrange-

ment of the lines is such that very short lengths of track feeder, say a few hundred yards, will greatly shorten the length of the return circuit to the generating station, they may be used to some advantage. They are usually of the same type of cable as the feeders for the rest of the system, except that, being subject to little or no pressure, the insulation can be made much lighter than in the feeder cables, and special precautions have to be taken to guard against damage by electrolysis

Another form of track feeder which has been used to some extent is composed of old rails heavily bonded together These can be laid in a wooden trough of sufficient size to hold them, and the trough filled with asphalt Steel rails have a resistance of from eight to thirteen times (usually about eleven times) that of copper, depending upon the chemical composition of the rail. But the low price at which old rails can frequently be bought will often make this type of feeder a very economical one to use. Before deciding upon this type, however, care should be

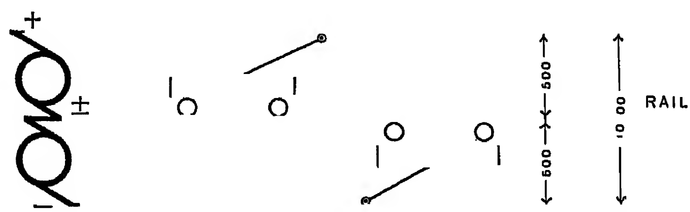


Fig 1020

taken to ascertain the nature of the ground in which it is to be laid, for if there are many pipes or underground obstructions likely to be met with, the laying will be found very troublesome and expensive, and will probably outweigh any advantage shown in the cost of material

Three-Wire System. — The distance to which power may be transmitted economically at 500 volts under ordinary circumstances is limited to about 6 miles In English practice this distance is reduced by the regulations of the Board of Trade in reference to the return circuit The limit to which power can be conveyed without exceeding the 7-volt drop in the return circuit required by the above regulations will be reached under the usual circumstances of load and service at about 3½ or 4 miles

There are, of course, instances where small or moderate loads may be transmitted even greater distances without undue cost of feeders, and without exceeding the 7 volts, but the above may be taken as the limit for average work

To overcome the above difficulties the three-wire system has been proposed (fig 1020) and in some cases used in the United States, but as yet has not been tried in this country

The principle upon which it works is practically the same as the Edison three-wire lighting system, and with two 500-volt generators in series would give a difference between the outside wires of 1000 volts, and a difference of 500 volts between either wire and the earth. Great difficulty is, of course, experienced in balancing the two sides of the

system, but the very large capacity which the track, acting as a neutral wire, has, renders a close balance unnecessary to the success of the system

In some instances the outgoing and incoming trolley wires (fig. 1020) have been respectively made the two outside wires. In other cases (fig 1021) the alternate sections of both trolley wires have been made the outside wires. The latter appears to give the best results in the way of balance

The economy of this system in the matter of feeders is not so marked as one would be led to suppose from the increase in the

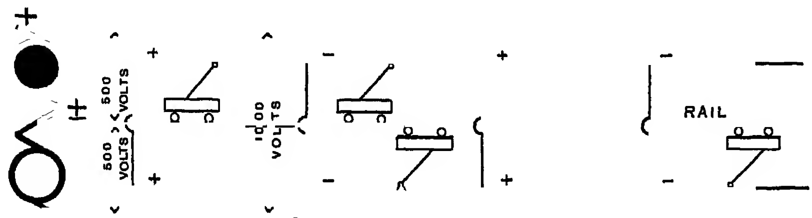


Fig 1021

voltage, as in the ordinary two-wire arrangement the track return is utilized to its full capacity. In the three-wire system it takes only the unbalanced load, so that as a fairly close balance is liable to occur at any time, it would be necessary to treat the feeders as a complete metallic circuit at the double voltage Therefore practically the same amount of copper would have to be used as with the ordinary two-wire system

Another type of three-wire distribution has been proposed (fig 1022), but the writer is not aware that it has been put into practice anywhere But it should work very satisfactorily if the cars were equipped with four motors each, as is often done with large bogie cars, either for city

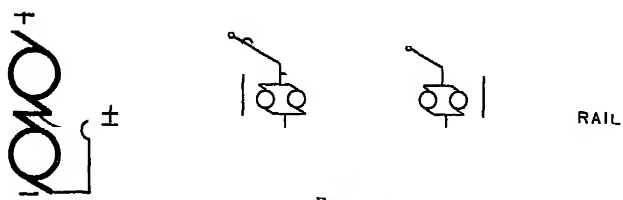


Fig 1022

or interurban service, in the United States It will be noticed that each car requires two trolleys, but would then be a self-balancing unit, two motors working on each side of the three-wire system In this case no special change from the standard controller would be required

Neither of these systems will effect any great saving in copper, but they might be used to advantage on outlying portions of a system to overcome the difficulties of a return circuit.

The four-motor self-balancing system might be used with considerable advantage in cases where there are a few outlying or interurban routes to be dealt with, as by providing the cars with a switch, which would put the pairs of motors in either series or parallel in reference to each other, the cars would work without difficulty with one trolley on

the ordinary parts of the system, and at the point where the return circuit commenced to cause difficulty could be changed to the three-wire system by throwing the switch and bringing into use the second trolley

It will be seen from the above that both boosters and the three-wire system are useful expedients for overcoming difficulties at particular points, but do not lend themselves to the working of an entire system If a considerable portion of the load is to be dealt with by some of these special methods it would probably be more advantageous to erect two or more generating stations, or to adopt a multi-phase system, with rotary converters or motor generators, as this enables full advantage to be taken of the economies obtainable by transmission at very high potentials.

In calculating the feeders for a three-phase system of tramways, those carrying direct current are dealt with in the manner just described, regarding the entire tramway system as being composed of a number of small independent tramways, each having its own generating station (sub-station) located as close as possible to its centre of gravity. These sub-stations, or transformer stations, owing to their small size, can usually be located without difficulty at their theoretically correct position The main generating station should be located as close as possible to the centre of gravity of the various sub-stations, but its position is usually solely determined by suitability of site in reference to the cheap production of power

The calculation of the multi-phase feeders from the generating station to the sub-stations entails a somewhat intricate calculation, which is fully dealt with in another section, as is also the general question as to the conditions under which it is advisable to use multi-phase transmission

It must be borne in mind that the power lost in the step-up and step-down transformers, and the rotary converters or motor generators, whichever may be employed, will be at least 20 per cent, to which must be added the cost of attendance in the sub-stations. To justify this increased working cost a corresponding advantage must be obtained in the ability to select a site for a generating station highly economical for the production of power, the use of larger and more efficient units, and the reduction in capital cost.

CHAPTER IV

METHODS OF INSULATION AND LAYING

The requirements of a system of insulating and laying feeder cables are —

First, reliability, freedom from possibility of faults, either from a failure of the insulation by chemical action, dielectric stress, or from external injuries.

Second, cheapness in first cost, ease and flexibility in laying, and adaptability to the various conditions met with in underground work.

Third, ease of locating a fault when developed, and cheapness in repairing the same when discovered.

All these features cannot be found to the highest degree in any one class of cable, or system of laying, and one quality must usually be sacrificed to some extent to obtain the others in the required degree. In each particular piece of work the advantages and disadvantages of the various methods must be carefully balanced before deciding which system will be most suitable.

The cables used for feeders in tramway work may be divided into three groups, according to the character of the dielectric used—solid, fibrous, and laminated

In the first class, rubber and vulcanized bitumen are used.

In the second, a covering of jute, hemp, or similar fibrous material, braided on or wrapped about the conductor, and then impregnated with an insulating compound

In the third, layers of thin paper, impregnated with insulating compound, are wound spirally about the conductor until the required thickness of insulation is obtained

The object of the compounds in the second and third class is to render the insulating material non-hygroscopic, which they accomplish to a greater or less degree All the above cables are usually covered with a sheathing of lead from 1 inch to 2 inch in thickness

Rubber cables for tramways, owing to their high cost and somewhat uncertain life, are practically obsolete Their use is usually confined to the feeding-in wires from the switch-pillars up the poles to the trolley wire, for which purpose exceptionally flexible cables, with a thin coating of high-class rubber and a moderate thickness of lead, are found to be the most satisfactory. Cables of vulcanized bitumen are being used to a considerable extent, and are often made without the lead covering, which is an advantage, for besides reducing the cost it eliminates all possibility of electrolytic troubles.

Cables of the second type, with various arrangements of woven and compounded insulation, were much used a few years ago, but their use has now been practically discontinued in favour of the third class of cables with paper insulation.

The third class of cable, with its strips of impregnated paper wound layer on layer to thicknesses varying from 08 inch to .2 inch, may almost be regarded as the standard tramway cable of to-day. It is a very satisfactory form of insulation, being moderate in price, reasonably flexible, and apparently does not deteriorate very rapidly There is, however, one drawback to its use, which is that it depends for its insulating qualities entirely upon the integrity of the lead sheathing

Many methods, and various compounds, have been tried to render the paper non-hygroscopic, but, so far, with only partial success. This is quite a drawback in tramway work, as the cables are frequently subjected to electrolytic action from the leakage occurring from the return circuit of the

tramway, which gradually destroys the lead covering, after which a breakdown of the insulation rapidly follows from the absorption of moisture.

This action can be minimized by the careful connection of the lead sheathing to the tramway rail, at points where the cable is positive in relation to the rail, and may be delayed for a considerable time by protecting the lead covering with a braided covering of jute, or hemp, and the waterproofing compound.

Wherever lead coverings are used in connection with tramway work, the lead should be of ample thickness, so as to resist this corrosive influence as long as possible. To overcome this difficulty the vulcanized bitumen cables have been developed, and appear to be giving good results, and although they have not been on the market for a sufficient length of time to speak with certainty as to their life, their manufacturers appear to have the highest confidence in them, as they are willing to enter into contracts for maintenance extending over a very long period, as much as twenty years in some cases, for a very low figure. And there seems every indication that this type will to a great extent supersede the paper cable.

Methods of Laying Cable. — The cables as above described cannot be laid direct in the ground, but must always be provided with some protection against mechanical injury, and which should preferably prevent or minimize chemical or electrolytic action upon the lead covering. There are three general methods of accomplishing this —

First, armouring.

Second, drawing into ducts.

Third, using what is known as the solid system.

The method most suitable to use requires careful consideration, and will be governed almost wholly by the local conditions.

Armouring.—This consists in wrapping spirally about the cable, in opposite directions, two layers of steel tape, each about $\frac{1}{64}$ inch in thickness. This steel armouring is protected from rust by a jute wrapping saturated in waterproof compound.

This armoured cable is laid direct in the earth at the bottom of a suitable trench, usually about 15 inches to 2 feet deep. The cables should be bedded in sand, or in some of the finer portion of the excavated material, which has been screened out for the purpose. It is also usual to lay over the top of the cable strips of wood, or a row of bricks, the object being to afford some extra protection to the cable, in case of excavations being carried out in its vicinity. The armouring itself will turn a pick point, unless it strikes it fair, in which case it is very apt to be pierced. The wooden strip or bricks call the attention of the excavator to the fact that there is something to be looked out for.

Armoured cables are fairly satisfactory and reliable, and are one of the cheapest forms of feeders, and can be used to advantage in Macadam roads or under footpaths, but where the cables have to be laid under the sett paving and concrete of a city street, the additional accessibility of the duct system, or the reliability of the solid system, will probably offset their greater cost.

Drawn-in System.—The drawn-in or duct system has much to recommend it, particularly for use on tramways where a large increase of traffic or extensions of the system are anticipated

Where there are a number of feeders following the same route, any one is rendered more easily accessible for repair than with the other methods of laying And although in most cases it does not in itself afford any great protection against electrolytic action, it allows the cables to be easily inspected and tested, and, if necessary, repaired. It facilitates the connection of the lead sheathing to the rails, so as to afford practically a large measure of protection against electrolysis These connections should not be made until the tramway is in operation, then such points of the cable as are positive in regard to the rail should be connected thereto.

Given a good quality of cable to start with, faults on tramway feeders should be of rare occurrence, and in practice it is often more convenient to draw out a length of cable and locate the fault by inspection, than to be obliged to locate it by the delicate capacity test needed to locate a fault in the armoured or solid systems The location of a fault by this method requires a high degree of personal dexterity, which continual practice is necessary to maintain In fact, faults should not occur sufficiently often, except in a very large system, to keep a man in good enough practice to make this test with certainty

The drawn-in system also entirely avoids the breaking up of the streets to locate and repair faults, and all the difficulties and inconveniences incident to this kind of work Therefore it presents great advantages for use in the busier thoroughfares of a city As has already been implied, the factors that go to make up the load on a tramway are not easily determined, nor can they be considered permanent, as the requirements of the riding public sometimes in a year or two change to such an extent that they seriously disturb the working of the feeder system, and a method which enables a rearrangement of the feeders to meet the altered conditions at a moderate cost has strong claims to consideration

A large number of different types of duct have been used They are usually from 2½ to 3½ inches in diameter, sometimes round and sometimes square Three inches is a very convenient size, and the round is in some respects preferable to the square

Ordinary cast-iron water-pipes, with socket and spigot joints, have been used, but have little to recommend them They are expensive in first cost, and the only compensating advantage is that they resist mechanical injury rather better than other types. They are no protection against electrolytic action, in fact they rather invite it. They do not in any degree form a secondary insulation to the cables, and a partial fault is at once made a dead earth

Earthenware Ducts.—Earthenware ducts of various forms have been largely used, in fact at the moment they may almost be called standard practice. They are usually made in lengths from 18 inches to 3 feet, and are sometimes made singly and sometimes in groups of from two to

sixteen ducts. These multiple ducts, at least in numbers above five, are usually made square, and Doultons are probably the best-known of the makers.

It is difficult to obtain these multiple ducts perfectly true, as they are apt to warp in the fire, and it is almost impossible to get the various sections to register correctly with the adjoining lengths It is not easy to work them around curves, as that necessitates mitring the various sections, which is a somewhat difficult piece of work to do neatly, and the result is not wholly satisfactory, as the curve consists of a number of short chords with more or less sharp corners

If the square type of multiple duct is used, it should be of very ample size to allow for these irregularities. But when any large number of ducts is required, this is undoubtedly the cheapest form, both in regard to cost of ducts and quantity of excavation and concrete required

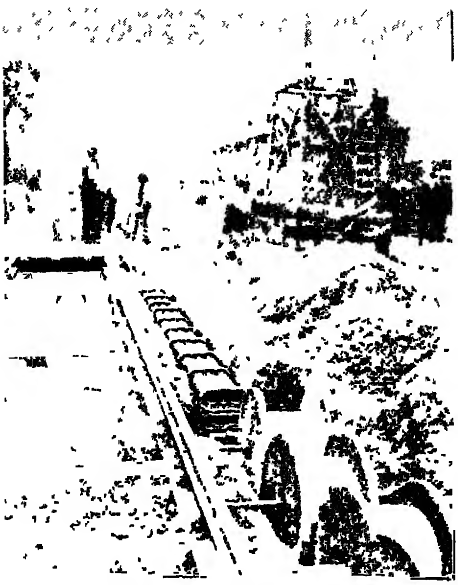


Fig 1023 —Laying the Sykes Conduit

All earthenware ducts should be embedded in concrete at least 2 inches thick, and preferably more, to give a certain amount of mechanical protection to the duct.

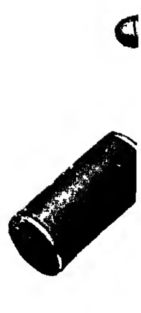
The joints in these square ducts are made by wrapping a strip of prepared canvas about them, and then bedding the joint in fine cement concrete A cradle of earthenware is often placed under the duct to hold the concrete in place The object of the canvas is to prevent the cement from being forced into the duct and forming fins in the interior

Single ducts are usually made with a socket and spigot joint, and so designed as to be self-centring The best-known type is made with what is known as the Stanford joint, and is practically a ball-and-socket joint moulded in asphalt This and the other types referred to are illustrated in the chapter on Electric Mains This conduit is easy to lay, but requires a good deal of concrete

Another type of multiple duct, known as the Sykes conduit (fig 1023), is shown In this a Stanford, or ball-and-socket joint, has been adapted to the use of a multiple duct This is an excellent form, is well made, and has been largely used. It is easy to lay, and has a considerable degree of flexibility for getting around curves and obstructions, but it takes a large amount of cement, and if very many ducts are to be laid requires a great deal of excavation

Great care should be taken in the inspection of all earthenware ducts, in order to obtain as smooth an interior surface as possible, as any rough-

Fig 1024   Asphalt Conduit, showing Spiral



Fig

To face iv, 84

ness of surface or blisters are extremely liable to damage the lead covering of the cables while being drawn in

After any ducts have been laid, and before they are covered in, it is always advisable to draw through them a rat and a spun-yarn mop The rat should not be more than ¼ inch less in diameter than the duct, and the mop should be of sufficient size to bring out any dirt or dust which may have got in in the laying

The earthenware ducts are on the whole very satisfactory, provided sufficient cement is used to afford mechanical protection. They are, however, damaged by any settlement of the ground, and can seldom be relied upon to be quite water-tight. They form to some extent a safeguard against electrolytic action, but they are not very reliable in this respect, as they are frequently porous in places, and this porosity has been known to absorb moisture or acids from the soil and set up local electrolytic action, forming practically a primary cell

Callender's Ducts.—Another form of conduit, made by Callender, is used to some extent It is usually made in multiple form in lengths of about 6 feet, and is composed of a bitumen cement which possesses a number of advantages It is moulded into shape, and the ducts are truer and straighter than the earthenware ducts It is also more waterproof and a greater protection against electrolytic action. It has considerable mechanical strength, but in general application and method of laying it is practically identical with the multiple-duct earthenware conduit, except that it is rather more economical in its use of concrete It is illustrated in the section on Electric Mains

Cement-lined Ducts—Another type of conduit has been used to some extent in this country, and very largely in the United States This is composed of a light sheet-iron pipe lined with cement about ⅜ inch thick It comes in lengths of about 6 feet, and is provided with ball-and-socket joints at the ends. It has an exceptionally smooth interior surface, and is easily laid. It is expensive, but moderately economical in the use of concrete, and must have an ample covering of concrete to protect it from mechanical injury

It has also some degree of flexibility, and the lengths in themselves can be curved slightly, and has ball-and-socket joints, so that pipes and underground obstructions can be dealt with with a moderate degree of ease The concrete lining is, however, apt to flake off and become porous

Asphalt Ducts.—Another system of ducts, known as the Howard conduit, has been brought out within the last year or two It is exceedingly ingenious in its method of manufacture, and possesses many advantages over the other types of duct now in use

It is composed of asphalt, and is made by placing a coil of heavy iron wire, like a spiral spring, in a mould and then pouring in the asphalt in a melted condition. The mould is then placed in a special machine rotated at a speed of 500 or 600 revolutions per minute, which causes the asphalt to spread itself in a uniform layer over the inside of the mould, entirely embedding the wire (fig. 1024)

The result is a duct of homogeneous texture, very smooth on the inside,

and with the stronger and coarser particles of asphalt on the outside Each length is fitted with a ball-and-socket joint. The method of jointing is also novel. A jointing-iron is used (fig. 1025), which exactly fits the ball-and-socket ends of the ducts. This iron is heated in a brazier and placed on the ball end of the duct, and the socket end is pressed up against it. The heat of the iron softens the asphalt at the ends of both lengths The iron is then removed and the ends are pressed close together, and an expanding mandril, covered with French chalk, is placed inside the duct to prevent the projection of any of the asphalt into the interior duct The result is practically a weld, the joint being the same size as the duct, and perfectly water-tight.

These ducts are easy to lay, as they are quite flexible, that is, under gentle but continuous pressure they can be bent to any desired curve This makes the avoidance of pipes and other underground obstructions remarkably easy, and also enables all curves to be taken with easy bends instead of a series of chords This conduit when laid has the following advantages —It is perfectly water and gas tight It is sufficiently flexible to yield to any ordinary subsidence of the soil without breaking It has a very smooth interior surface, and is full-bore throughout its entire length The material from which it is made has high insulating properties, which almost entirely protect the cable from electrolytic action The insulation is sufficiently high, so that even should a breakdown occur between the conductor and the lead sheathing, the cable can be worked until it is convenient to repair the fault

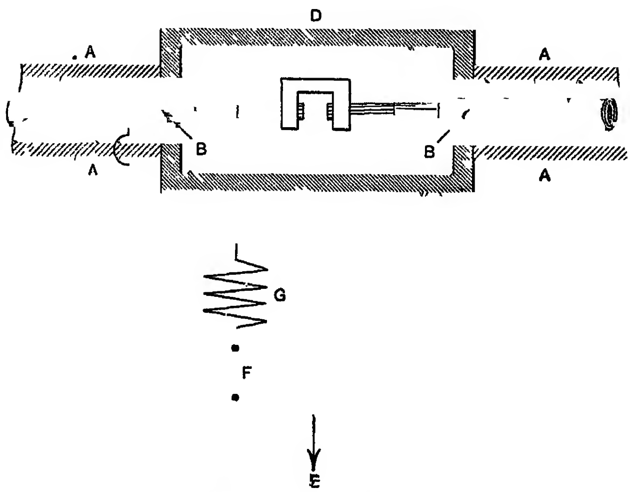


Fig 1026.—Fuse Connections

Howard Isolating System.—By the use of the devices shown in fig 1026 the faulty section can be automatically located D represents an asphalt-lined joint-box, connecting two lengths of lead-covered cable B, drawn into the asphalt ducts A. The lead sheath of the cable is insulated from the joint-boxes by the asphalt, and the lead covering of the lengths of the cable B is connected to the earth at E through a resistance G of 1 ohm, and an indicating fuse F set to blow at any convenient amperage, say 25 It will be noted that the lead sheathing of the cable is not continuous, but is divided into sections at each joint-box. If a fault occurs between the conductor and the lead sheathing the current passes to earth through G

and F, blowing the fuse F. The lead is now insulated from the earth only by the asphalt duct, which has sufficient insulation to render working possible.

That the cable contains a fault will be easily seen from the daily test from the station, and the section upon which the fault has occurred will be located by a simple inspection of the fuses. The resistance G has the effect of reducing the electrolytic action to a negligible quantity. The necessary fuses and resistances are fitted up on a small insulating block mounted in a convenient position inside the drawing-in box (Fig 1027.)

This system of conduit has not a great deal of mechanical strength and will not resist more than a very slight blow, and consequently needs to be very thoroughly protected by a shield of concrete, but as the joints are of the same size as the rest of the duct they lie very close together, and require considerably less concrete than do the ducts with Stanford joints The Howard conduit is somewhat expensive in first cost, but this should be compensated to a great extent by the facility in laying It seems to possess many advantages over other forms of duct

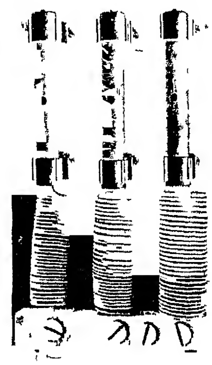


Fig 1027 —Fuse Block.

Drawing-in Boxes.—The use of a drawn-in system necessitates the provision of drawing-in boxes at intervals, which intervals must depend largely on local conditions.

Drawing-in boxes are usually brick chambers built below the level of the street and provided with cast-iron manhole covers These covers usually have wooden blocks fitted into them to prevent their being slippery if placed in the roadway, and if placed in the footpath the cover is usually filled up with concrete Their size will obviously depend greatly on the number of ducts running into the box, but they should be not less than 2 feet 6 inches in length in the direction in which the cables are to be drawn, and their width should be equal to the over-all width of the ducts taken collectively.

Ventilation of Ducts.—One great drawback to the use of a drawn-in system is the liability of gas to collect in the ducts, which gas, through some causes not yet fully determined, takes fire and causes an explosion which often does great damage. This can be guarded against to a great extent by a careful system of ventilation of the ducts A simple and convenient method of accomplishing this is shown in fig 1028, and is applied at each point where the feeding-in wires pass into the poles, and with very little extra expense could be applied, if required, much oftener.

As a considerable amount of energy is lost in the cables, and is transformed into heat, a circulation of air will be set up by this means. Some of the ventilators will act as in-takes and some as out-takes

Solid System.—What is known as the solid system has been extensively used during the last few years, and seems growing in favour. It consists of laying the cables, either singly or in groups, in a shallow trough which is

filled with bitumen, and the top covered in with some suitable material These troughs have been made of cast-iron, creosoted wood, earthenware, and asphalt, and the selection of the most suitable material will be governed largely by local conditions and cost. Electrically the system depends upon the bitumen with which the trough is filled.

In some cases the troughs are rectangular, and in others semicircular in section. Where there are many cables to be laid side by side the rectangular section will be found the most economical, but with a single cable and test wires a semicircular section will be very satisfactory.

This solid system, although somewhat expensive, has much to recommend it, and will probably be found freer from break-downs than any other system, and it is entirely free from electrolytic troubles. It also affords a very considerable amount of mechanical protection to the cables, and in cases where the maximum demand upon each feeder can be determined with a reasonable degree of accuracy will be found entirely satisfactory But should extensions or alterations be required, or the traffic develop to such an extent as to demand additional feeders, the expense of providing them is much greater than in the drawn-in system

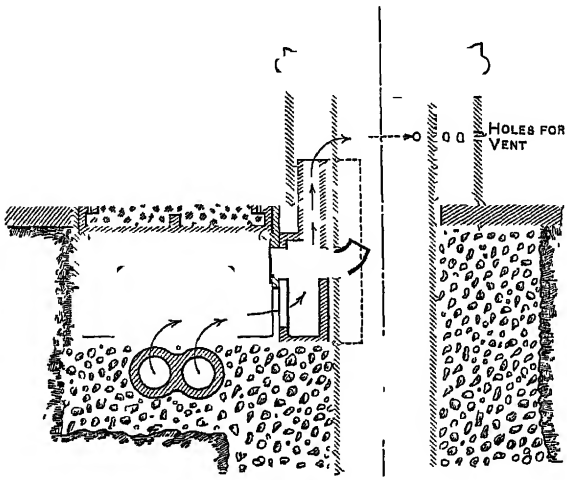


Fig 1028

When faults do develop they are somewhat difficult to locate, as it can only be done by a capacity test, which, as above stated, requires constant practice to carry out with accuracy. The repair of the fault also means breaking up the street for a greater or less distance, and the consequent expense to the owners and inconvenience to the general traffic.

A weak point in this system is the necessity for the use of bridge-pieces, which are to prevent the lead sheath of the cables from coming in contact with the troughing, for the bitumen with which the trough is filled cannot be regarded exactly as a solid. It is a very slow-moving fluid, and it does not afford very much support to the cable, the entire weight of which rests on the bridge-pieces, at which point faults most often develop

The Howard asphalt troughing (fig. 1029) being in itself an excellent insulator, these bridge-pieces can be omitted. The troughs can consequently be made somewhat smaller, with considerable saving in the quantity of bitumen required

Any convenient form of covering can be used with this troughing, but a thick layer of asphaltic concrete is the cheapest and most satisfactory.

For, being put on hot, it forms a weld with the sides of the troughing, making the trough absolutely water-tight.

These asphalt troughs are made with a light sheet-iron casing to help

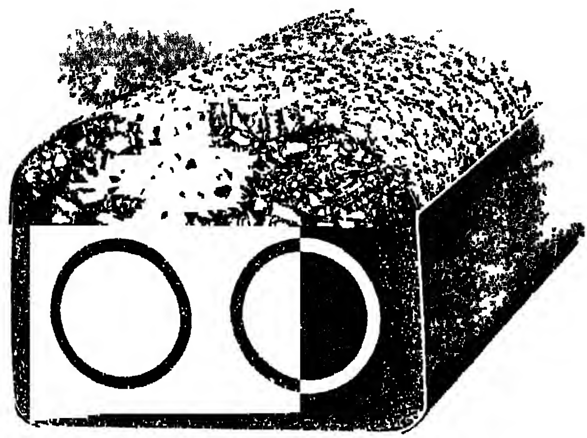


Fig 1029 —Howard Asphalt Troughing

them to retain their shape until laid The sheet-iron casing can be removed and the troughs warmed and bent to any degree of curvature which may be convenient (fig 1030), and the various lengths of troughing are

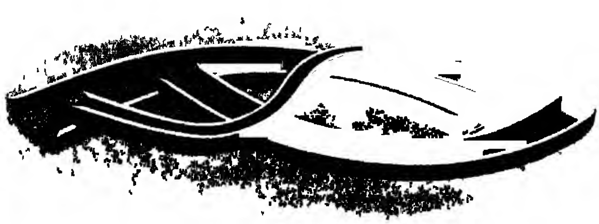


Fig 1030 —Curved Lengths of Troughing

welded together in the manner described for the ducts Experiments have been made with this system of troughing with a cable insulated with a few layers of paper and entirely without lead covering

Some remarkably satisfactory tests have been made with this system,

and some lengths have been laid, and it promises to come into quite extensive use in the near future

Joints.—It is usual to employ one of two methods in making joints on a tramway cable. In the first, the lead covering is removed for a length of 4 or 5 inches, and the insulation for about half of this distance. The ends of the cable are then passed into a small iron box of suitable dimension, provided with stuffing-boxes and a removable cover The stuffing-boxes are made tight on to the lead sheathing, and the joint between the conductors is made by a screw clamp of copper or brass, and having a contact area on each end of the cable of at least 1 square inch for each 100 amperes to be transmitted The entire box is then filled with melted bitumen and the cover fitted on

In the second method, the cable ends are prepared in a similar manner, and a piece of lead pipe of convenient length, and a couple of inches more in diameter than the cable, is passed over it. The joint between the conductors is made as described, and the lead piping slipped along to cover the joint A wiped joint is then made between each end of the lead pipe and the lead sheathing A hole is made in the lead pipe, and the annular space around the cable filled with melted bitumen, and the hole soldered up.

Either form is very satisfactory when properly done The first requires rather more room in the drawing-in box, but is much more easily made and disconnected, which is an advantage for testing and repairs The difficulty with the second type of joint is that, owing to the confined space in which it usually has to be made, it is not easy to be sure that the wiped joint is free from pin-holes and is perfectly water-tight, and for repair work it is not always easy to obtain a plumber of sufficient skill to make a thoroughly satisfactory job

Position in Street.—Where armoured cables or the solid system is used, it is much preferable to lay the cables under the footpaths, on account of their increased accessibility when so laid When the footpath is not available, as is often the case, as the electric-light engineer has usually pre-empted this location, the Macadam road is the next choice Laying under sett paving and concrete should be avoided where possible, and these systems should never be laid between the tramway rails, as the tie-bars and cross-bonding, and the continued movement of the tram-cars, render it extremely difficult to get at the cables

The drawn-in system may be laid under the footpath, if this space is available, but, as it requires more depth than the other systems, trouble may be experienced from cellars running under footpaths, and a large number of service pipes are sure to be interfered with, but the position somewhat reduces the liability to electrolytic troubles, and where span-poles or side brackets are used, simplifies the feeding-in arrangements

When the ducts are put in at the same time that the tramway is being laid or relaid, they may often with advantage be in the foundations of the permanent way, as this method saves a large amount of excavation and the most expensive part of it (the removal of the road metal or paving). Also, the concrete foundation for the tram lines forms a most efficient

protection for the ducts. Care should be exercised to prevent the drawing-in boxes from coming between the rails. They should be between the tracks with double lines, and in the margin with single lines.

It is not practicable to pull cables through ducts having much curvature. The middle ordinate of the curve should not usually exceed 5 per cent of the chord. Where tramway lines make a sharp curve, the ducts are usually laid to follow the tangents of the curve, and a drawing-in box located at their intersection, and sharp bends made in the cable or joint-boxes are used, having the stuffing-boxes at suitable angles

CHAPTER V

MISCELLANEOUS

Overhead Feeders.—These have not been used to any extent in this country, largely on account of their objectionable appearance, and certainly a line of poles carrying a number of heavy feeders is not a pleasing sight

Overhead feeders might, however, be used with great advantage from an economical stand-point for suburban or interurban routes where appearance is not the first consideration, as when properly put up they give no particular trouble either in operation or in cost of maintenance.

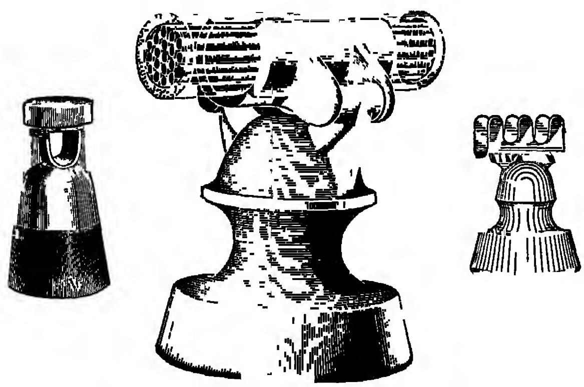


Fig 1031 —Types of Insulators for Overhead Feeders

When they are used, what is known as weather-proof wire is generally employed This is a cable insulated with two or three braided thicknesses of jute, each thickness thoroughly impregnated with a compound This insulation has considerable mechanical strength, and many of the compounds enable the insulation to resist the weather for a considerable number of years The covering of the wire is not in any way depended upon for insulation, except for accidental contact either of persons or of other wires The insulation of the feeder depends upon the supports at each pole

Three of the most largely used types of these are shown. The insulating material itself is the same as is used for the trolley-wire insulators and fittings. These insulators (fig. 1031) are screwed on to pins of either wrought or cast iron. Where only the single feeder is required, it may be carried on top of the pole in span-wire construction, or in bracket construction on the short arm on the opposite side of the pole to the main

bracket. If several wires are required, short cross arms with a suitable number of pins are bolted to the poles

Test Wires.—Under the Board of Trade regulations, a small wire is run from the end of each tramway line to the generating station for the purpose of measuring the fall of potential in the return circuit These test wires are usually 7/20, and insulated in a similar manner to the main cables, and are generally laid like them Where possible they are made up into multi-core cables to save expense in the laying. They are frequently run into each section box, and when so arranged are very convenient for testing different individual sections of the feeders.

Where a telephone system from section box to section box is installed, the telephone wires are often made up into the same cable with the test wires, thus forming a three-core cable. The potential used in the test wires is, of course, very low, not exceeding 7 volts, so that a high degree of insulation is not required But the insulation should be thoroughly reliable, and as much care taken with it and the lead covering as with the main cables

The details of cables, methods of laying and jointing, and the localization of faults, are more fully dealt with and illustrated in the chapters on Electric Mains.

5. Surface-Contact Systems

CHAPTER I

INTRODUCTORY

The earliest method of conveying electrical power to a moving vehicle appears to have been by means of a third rail supported on wooden blocks close to the surface of the ground It was very soon discovered that this method of transmission was limited in its application, and that it was wholly unsuited to use in connection with tramways, as it was necessary to place the conductor so that the danger from accidental contact would be reduced to a minimum.

There were two obvious methods—one to carry the conductor overhead, and the other to place it beneath the surface. Both ideas proved entirely practicable, but the overhead system, on account of its low cost, was rapidly developed, and soon became the standard practice

It was soon demonstrated that the conductor or conductors could be successfully worked when placed in an open conduit beneath the surface of the street or road, but to ensure reliability a large well-drained conduit was required, which entailed a very heavy capital outlay This state of affairs naturally led to a demand for a system that would avoid the use of the unsightly, and, as then erected, dangerous overhead wires without entailing the prohibitive cost of an open conduit To meet this demand inventors and engineers endeavoured to develop what is now known as the Surface-Contact System

This system essentially consists of a sectional conductor laid nearly flush with the surface of the street, or in a small shallow conduit, a continuous conductor connected with the generating station, and insulated in any convenient manner, a series of switch devices which automatically, as the car passes them, make a connection between the continuous conductor and the respective sections of the sectional conductor when immediately beneath the car.

It will be readily seen that, owing to the many difficulties, both mechanical and electrical, to be dealt with, the proposition affords a wide field for the application of mechanical and electrical ingenuity. In fact, something like one thousand patents have already been granted in connection with this subject, but the difficulty of the problem has been so great that up to the present time none of the solutions offered have proved more than a qualified success. It is obviously beyond the scope of

this work to describe them all, even briefly, but a number of systems have been selected for description which may be regarded as typical of their class, and details are given of nearly all of those which have been tried, either in actual service or on experimental lines

The earliest inventors in the field were the late Dr John Hopkinson and Messrs. Ayrton & Perry, who both devised what were in effect surface-contact systems, but their object appears to have been to prevent excessive leakage from a long length of third rail.

Surface-contact systems may be divided into the following general classes, according to the method in which they make connection between the continuous and sectional conductors —

1 *Mechanical.*—In which the switch is actuated by the weight of the car, or some form of striking gear.

2. *Magnetic.*—In which the switch is actuated by means of a powerful electromagnet carried on the car.

3. *Electromagnetic.*—In which the switches are actuated by fixed electromagnets located in convenient positions beneath the surface of the road

Many of the systems combine two, and in some instances all three of the above methods

There are two general forms of making connection between the sectional conductor and the moving car. In one case the sectional conductor is mechanically continuous, having but short insulated gaps, and the contact is made by a brush or wheel carried on the car In the second method the sectional conductor consists of a series of studs projecting slightly above the surface of the roadway, and usually placed 6 or 8 feet apart. The collector in this case is a skate-shaped shoe, of sufficient length to reach between two of these studs, and often so designed as to come in contact with three or four at the same time Either of these methods of collection are applicable to most systems, although the stud system has been more generally used

The waste of power in surface leakage is a factor that at first sight would appear to be a serious drawback in all systems of this class, but in practice it is found that under the worst conditions this does not reach an amount that would seriously interfere with the success of the line, varying from practically nothing in dry weather to about 5 amperes per car at 500 volts, the skate being in contact with two studs, and would probably not exceed 5 per cent of the total power required under average conditions This, although a serious item on a large tramway, is not prohibitive. The amount of leakage current will not vary greatly whether the sectional rail and brush, or the skate and contact-stud be used, for it is not practicable to raise the studs enough above the surface of the street to keep the skate clear of mud and water, and as the skate is always alive it presents as much surface for leakage as would a sectional rail.

Closed Conduits.—Another series of inventions, having the same object as the surface-contact systems, were known as Closed Conduits. They were small shallow conduits, having one or more continuous conductors, and they were provided with some means for keeping the conduit closed so as to exclude mud and water, except at that portion of the

conduit beneath the car necessary to admit the plough to make connection with the conductors.

In the study of surface-contact systems they should be considered entirely from a tramway stand-point, for, if the line should be built on a private right-of-way, the instances under which it would be advisable to replace the simple third rail by a complicated surface-contact system would be practically non-existent. This will enable us to dismiss a large number of systems with a very few words.

The fundamental requirements of a surface-contact system are as follows —

1. Certainty of the contact being established
2. Certainty of the contact-stud being cut out after the car has passed
3 Minimum projection above the surface of the street, and minimum amount of metal surface exposed.
4 Moderate first cost
5 Simplicity and minimum number of moving parts.

In regard to the first requirement, it has been established that the certainty of pick-up is greatly enhanced by energizing the stud or sectional conductor before the collecting device touches it

The second requirement is in some respects even more important than the first, for if a stud or sectional conductor is left alive in the street, serious or even fatal accidents, either to horses or foot-passengers, will undoubtedly result This, besides rendering the tramway liable for damages, would certainly cause the authorities to prohibit the system

CHAPTER II

MECHANICAL SYSTEMS

Practically all mechanical systems depend for their success on the use of a conduit of greater or less dimensions. It will be seen that this must be so from the inherent nature of the device employed, otherwise the contacts would be actuated by the ordinary street traffic This renders most mechanical systems very expensive, as the design and construction of a conduit, particularly in connection with the points, crossings, and junctions, is a matter of difficulty and expense So that if a conduit is needed at all it would seem more advantageous to use the simple open conduit of ample dimensions, which is known to work well.

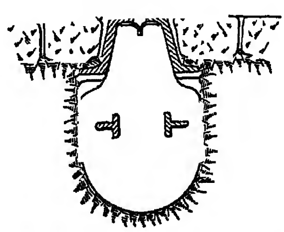


Fig 1032 —Conduit Closed by Flexible Lips

The mechanical systems may be divided into the following groups:—

1 Closed conduits.
2. Those in which a stud is depressed by means of the collecting device.

3. Collapsable tubes.
4. Those in which the mechanism is actuated by the wheels of the car.
5. Those in which the contact-stud rises above the surface of the road.

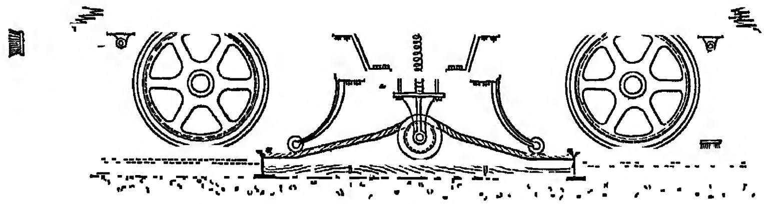


Fig 1033 —Conduit Closed by Flexible Strip

6. Those in which the switch mechanism is put in motion by the action of the collector or a striker.

Many of the mechanical systems combine features of several of the above groups.

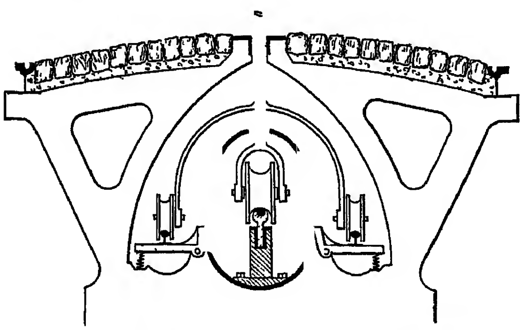


Fig 1034—Conduit Open to admit Collector Wheel

(1) **Closed Conduits.**—Fig. 1032 illustrates a type of conduit which was kept closed by flexible lips of rubber or other suitable material, which were pressed aside by the action of the plough or collector, the current returning by the rails. Air was continuously pumped into the conduit under pressure, which would blow out water or dirt when the lips were open to admit the plough.

Fig 1033 illustrates a type in which the conduit was closed by a flexible strip, either of insulating material or steel, in which latter case the conduit was much larger than that shown. This flexible strip is raised by a roller

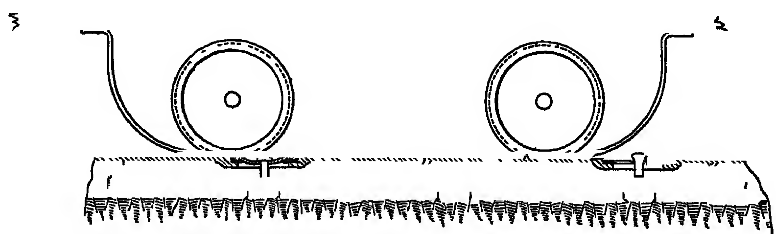


Fig 1035 —Spring Diaphragm depressed by Direct Pressure of Skate

as the car proceeds, which roller makes contact with the conductor. Two small rollers, in front and behind the collector, prevent the strip from being lifted too far in advance of the car, and press the closing strip into place after the car has passed. A brush is provided to remove any mud or dust from the top of the conduit immediately before the cover is raised.

In fig. 1034 another type is shown in which a pair of auxiliary wheels

on the contact-plough press upon rails, which opens the conduit for the admission of the collector, springs close the conduit after the collector has passed.

(2) **Depressible Stud.**—In fig. 1035 the contact-stud is carried in the centre of a flexible diaphragm, and by the action of the skate is pressed down in contact with the feeder This system would easily be worked by the street traffic, and the amount of movement that it is possible to allow in a diaphragm is insufficient to break an arc if formed.

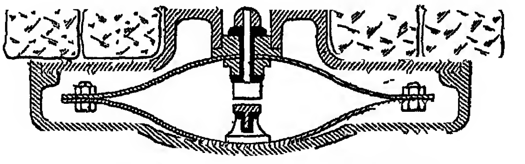


Fig 1036 —Collapsable Conduit Steel Tube

(3) **Collapsable Tubes.**—Figs. 1036 and 1037 show examples of this group In fig 1036 the walls of the tube are of metal, and the section of the tube is similar to that of an elliptic spring, and when subjected to pressure by the collecting skate or wheel acts in a similar manner. The live conductor is carried on insulators

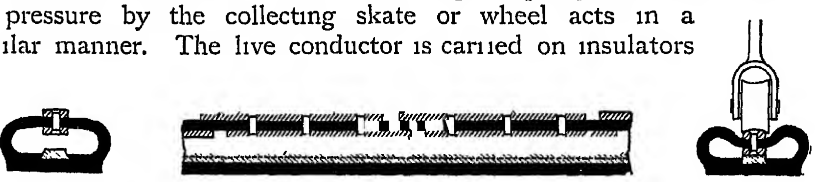


Fig 1037 —Collapsable Conduit of Rubber Tube

at the bottom of the tube, and the sectional rail is pressed down upon it by the action of the collector.

Another type is shown in fig 1037 in longitudinal and transverse sections. The tube in this case would in all probability have to be

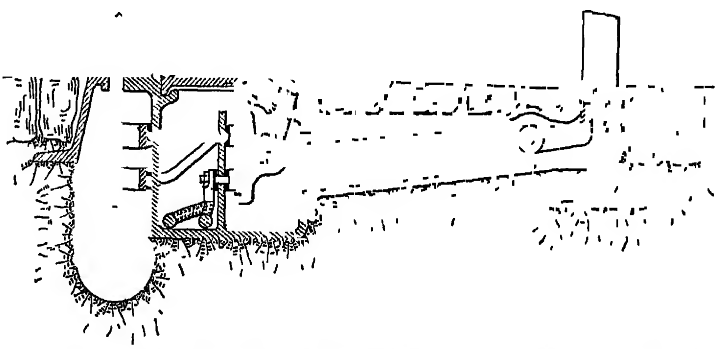


Fig 1038 —Switch actuated by Flange of Car Wheel acting through Lever Gravity Release

made of rubber and protected by a conduit, which facts taken together would render this system impracticable

(4) **Actuated by Car Wheel.**—In fig 1038 is shown a good example of this group. A third rail is placed beside the running rail, filling up the groove. This third rail is depressed by the action of the flange of the car wheel, thus making connection between the feeder and two

contacts in a small conduit conveniently placed, from which contacts the current is collected by means of a suitable plough. The third rail returns to its position by the weight of the lever and the action of a spring. With careful attention to detail this system might be made to work. As there is no particular need for placing the contacts in a

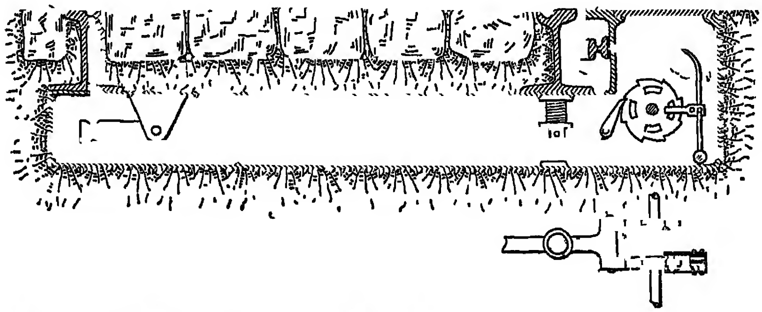


Fig 1039 —Car Wheel actuates Ratchet-Wheel, alternately Switching Current On and Off Conductor

conduit they could quite readily be arranged as contact-studs in the roadway. Owing to the great weight available on the car flanges it would be possible to make the springs so stiff that the ordinary traffic could not work the switch.

In fig 1039 a system is shown whereby the action of the flanges

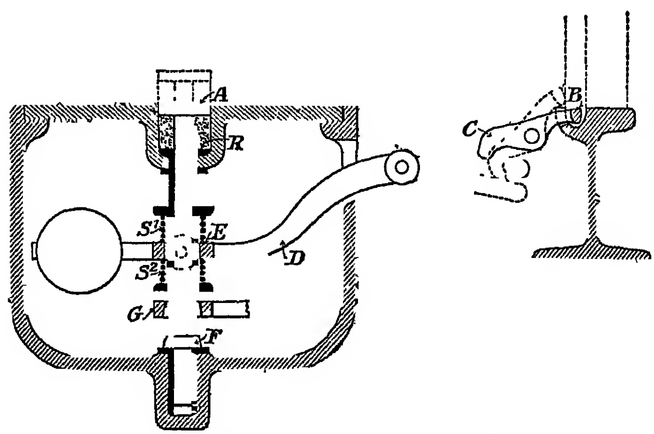


Fig 1040.—Car Wheel acting through Lever raises Contact Stud

of the car wheel, working through a system of levers, actuates a pawl, which moves a ratchet-wheel one step at a time, alternately switching the current on to and off of a sectional rail laid in a small conduit, from which it is collected by a brush. The pawl is so arranged as to work two ratchets, one step apart from each other, so that the movement of the pawl which cuts the advance section into circuit cuts the rear

section out of circuit. It is obvious that this system can only be used in connection with a four-wheeled car, and that all cars must have the same wheel base.

Fig 1040 shows a system that might be included in either this group or the next one The contact-stud A is flexibly connected by means of ring E to weighing lever D, which is actuated by bell-crank lever C,

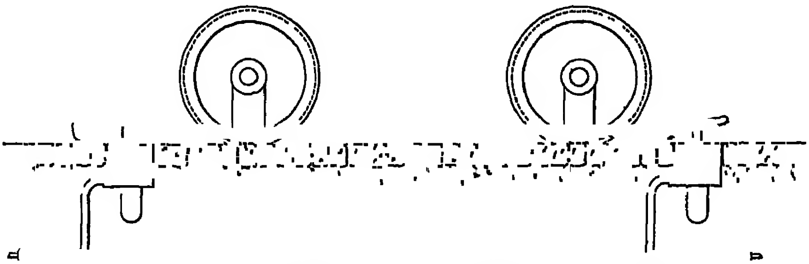


Fig 1041 —Skate depressing Contact-Stud forces Advance Stud to Rise

which is attached to a continuous flexible strip or treadle B. This rests in the groove of the rail until it is wedged out by the action of the flange of the car wheel as it passes. The bell-crank lever then depresses one arm of the lever D, raising the spindle carrying the contact-stud A, an enlargement of the spindle F makes electrical contact with the feeder G The springs S^1 and S^2 maintain a firm yet flexible contact between the top of the stud and the collector-skate, and when the stud is in its normal position forces it down against the rubber washer R, to assist in excluding moisture from the switch mechanism. This system is not very practical, as, when the wheel flanges became a bit worn through service, they could not be depended upon to raise the stud to its full height

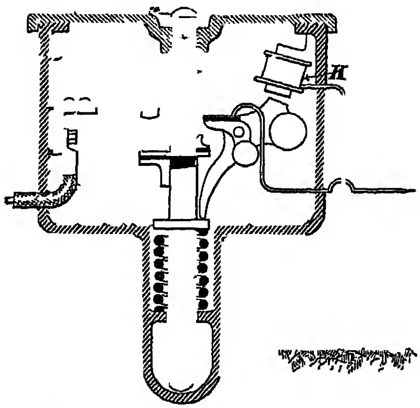


Fig 1042 —Section of Contact-Stud and Box

(5) **Rising Contact-Stud.**—Figs. 1041 and 1042 show an example of this class. It is operated by a skate nearly the length of the car. The short length at the rear end of the skate is insulated from the rest and practically touches the roadway. The pins are provided with springs which tend to force them upwards some 3 or 4 inches above the paving They are normally pressed down flush with the paving and latched in that position, and in such position are out of circuit The pressing down of a pin by the rear end of the skate unlatches the next one in front, by sending the current through the magnet coil K, fig. 1042. The pin then flies up and makes contact with the skate, and is in its turn pressed down, releasing the advance pin.

The Anderson system is similar to the preceding one, except that its

switches are entirely mechanical. The working of the system is shown in fig. 1043 The switch mechanism is contained in a cast-iron box of suitable dimensions, 3 feet long by 1 foot wide by 1 foot 8 inches in depth. The distance between these boxes is regulated by the length of the car In the line installed at Leeds they were placed 17 feet apart. The boxes were provided with a checker plate cover, which could be removed with lifting keys in the usual way. No attempt was made to keep the boxes water-tight. The boxes were connected together by a three-way Doulton conduit laid on edge The two steel wires, W and W, were carried through the upper and lower ducts, and the electrical conductor was carried through

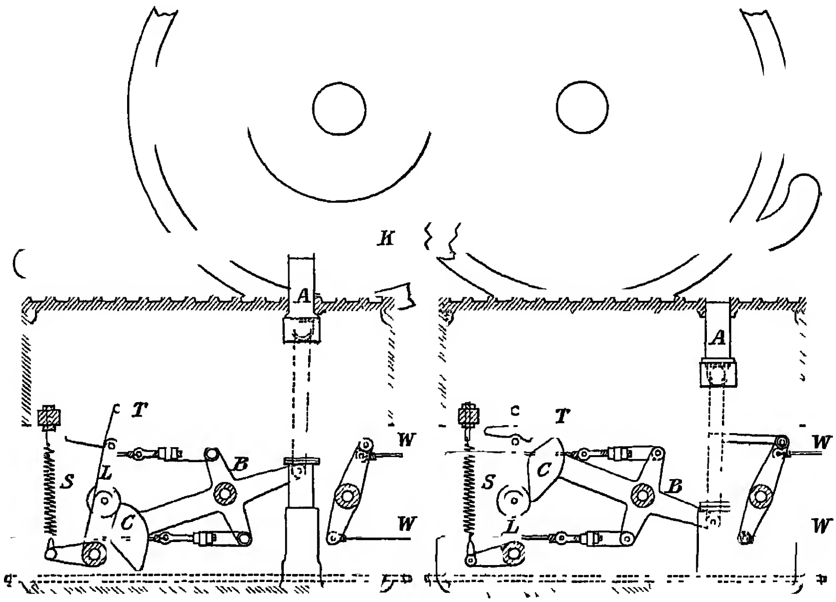


Fig 1043 —Switch-Box of Anderson System (Leeds)

the middle duct. The electrical portion of this system was quite simple. The stud A was a hollow casting provided with an insulating bushing at each end, and an air-space between A renewable cap of brass was fitted to the top of the upper insulating bushing, and the conductor carried down through the stud and connected to a brass terminal which formed the lower portion of the stud. A second brass terminal was secured to the side of the box, but insulated therefrom and electrically connected with the main feeder As the stud was forced up by the switch mechanism, these brass terminals came into contact and closed the circuit between the feeder and the brass cap on top of the contact-stud. The collector-skate, which was carried on the car, consisted of sheet copper riveted to a channel steel frame. The collector-skate was considerably wider in the centre than at the ends, to enable it to keep in contact with the contact-stud even when going around sharp curves. This skate was rigidly attached to the car and carried about 4 inches from the ground, and was provided at the rear end

with a ramp, which was carried down to within about ½ inch of the setts The rear half of this ramp was insulated from the rest of the collector

The working of the system was as follows:—The first contact-stud was raised by hand, or by a suitable lever, into contact with the skate The car was then started, the current flowing through the electrical contacts above described, the brass cap on the contact-stud, the collector-skate, through the motors to the rail. As the car proceeded the ramp on the collector-skate K depressed the contact-stud A, which actuated the double bell-crank lever B The lever B carried on its end a cam C, bearing on a roller carried on a single bell-crank L. The upward movement of the cam C forced the lever L to the left, thus by means of the rod T and wires W W the double bell-crank lever B in the advance box was moved in the reverse direction to the lever B in the first box, thus forcing the advance stud A upwards When the centre point of the cam C in the first box passed the centre of the roller on level L, the spring S came into action, causing the cam C to be forced upward quickly, which motion forced the contact-stud A sharply down to its lowest point At the same time the cam C in rising disengaged the rod T from the lever L In the advance box the action of the cam was reversed, the centre point of the cam having passed the centre of the roller L, the spring S forced the cam C sharply down, and the lever L to the right so that it engaged the rod T, which fell and caught lever L by its own weight. The rapid downward motion of the cam threw the advance contact-stud A sharply upward, and made contact with the collector-skate K, against which it was held by the spring S acting through the roller on lever L, cam C, and double bell-crank lever B

It will be noted that the pressure against the collector-skate is a flexible one, and is capable of following any irregularities in the skate The forcing down of the contact-stud A in the first box breaks the electrical contact between the contact-stud and the feeder wire with absolute certainty, and as the length of the collector-skate is so proportioned that the advance stud comes in contact with the collector-skate before the first stud reaches the insulated portion of the ramp, the electrical circuit is never broken in the box.

The action was then repeated in the succeeding boxes, and when installed on a single track, two sets of mechanism and two contact-studs were provided in each box, the mechanism so arranged as to work in opposite directions.

The serious inherent drawback to this system is its inability to run backwards farther than the length of the skate, and if the current should be cut off momentarily from the station while a car was ascending a gradient, and the car allowed to run back, as might easily happen, a contact-stud would be left sticking up in the street and alive, and this would form a serious danger to traffic It would only be possible to start the car again by pushing it by hand to the live contact-stud. It would also be impossible to cut the current off from the live stud, for if it was forced down an advance stud would promptly rise. The details of the system, particularly the electrical portions, were not well worked out, to which to some extent must be credited the failure of the system.

The system as installed at Leeds was not found wholly satisfactory. The mechanism was sluggish in action, particularly when starting a car, and the cast-iron boxes having been electrically connected to the rails, in compliance with the Board of Trade requirements, short circuits were frequent, and after two trials the system was abandoned.

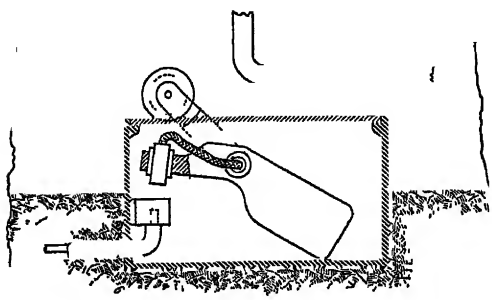


Fig 1044 —Contact-Closed Switch by Depressing Arm Gravity Release

In the system shown in fig 1044 a number of switch-boxes are located along the bottom of a suitable conduit Through a stuffing-box in each of the contact devices projects an arm, which carries an ordinary trolley wheel and harp The action of the skate depresses the trolley wheel, closing the circuit in the switch-box After the skate has passed, a weight restores the arm and trolley wheel to their original positions

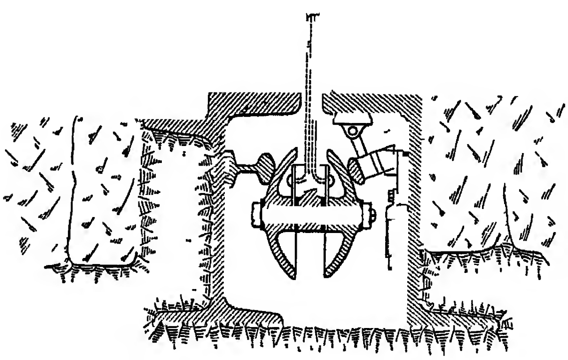


Fig 1045 —Contact-Skate Closed Switch by Wedge-Action Gravity Release

In the system shown in fig 1045 a continuous conductor rail is secured to one side of the conduit On the other side of the conduit are a series of contact-studs connected with the feeder Between them hangs a sectional conductor so pivoted as to be free to swing against the contact-studs. A double wedge-shaped skate is used, which forces the swinging conductor against the contact-stud, which sectional conductor returns to its position by gravity after the skate has passed

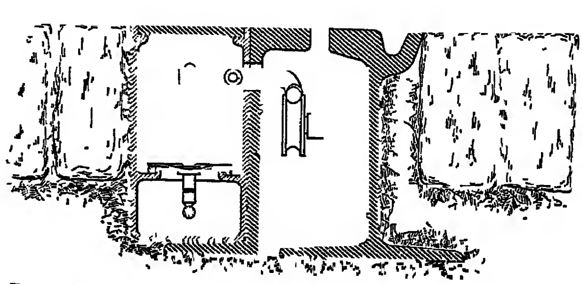


Fig 1046 —Contact in Separate Chamber, with Flexible Diaphragm actuated by Wheel through Lever

In fig. 1046 the sectional conductor is raised by the action of the collector-skate, which in this case takes the form of a wheel The raising of the sectional conductor by means of a bell-crank lever completes the circuit between the feeder and the sectional conductor.

A flexible diaphragm is used to seal the contact-box proper The conduit required is very small, but has to be somewhat carefully drained. The collector may be provided with a brush to keep the conduit clear of mud

The system shown in fig. 1047 is one of the interdependent class. A trolley wheel runs on a sectional conductor in the conduit. This trolley

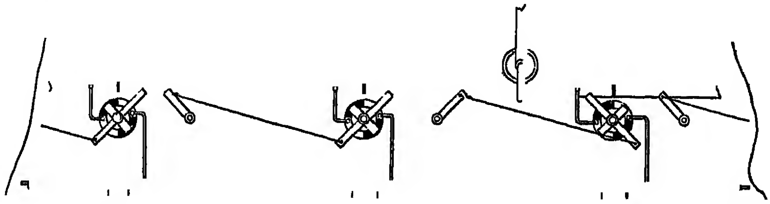


Fig 1047 —Wheel Running on Sectional Conductor Switches On and Off Current by Mechanical Striker

strikes two levers in quick succession The action of the first is to cut out the rear section of conductor, and that of the second to cut the advance section into circuit.

The Stetson system requires a shallow conduit about the depth of the rail, and 5 or 6 inches in width. This can be of any suitable design At intervals of about 10 feet, varying of course with the length of the car, switch-boxes are placed. These are located on both sides of the conduit. The rails are not used for the return circuit.

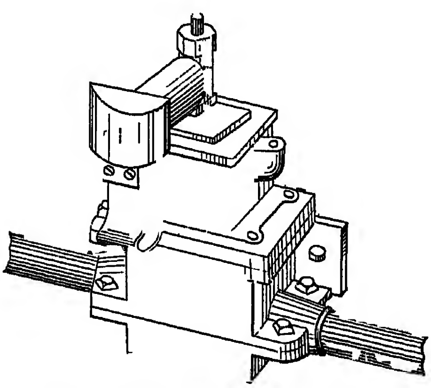


Fig 1048 —Stetson System—Contact-Box closed

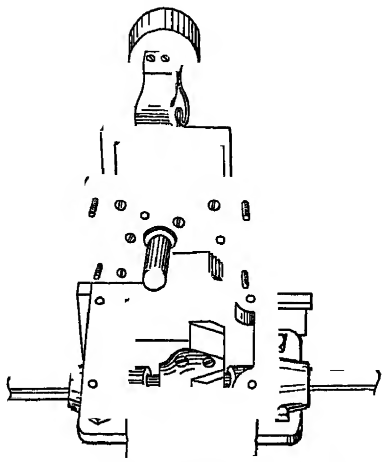


Fig 1049 —Stetson System—Contact-Box open

These boxes were simple in construction, and are shown in figs. 1048 and 1049. An insulated cable runs down each side of the conduit apparently simply laid loose Where it is desired to put switch-boxes, the insulation was removed and the box clamped about the cable, a stuffing-box at each end keeping the water out of the boxes. To the core of the cable is secured a brass clamp having two upwardly-projecting tongues Through the cover of the box passes a vertical spindle, carefully insulated from the box, and carrying an arm and semicircular contact-piece at its upper end, and a flat copper-leaf brush at its lower end. A torsion spring

maintains this brush midway between the two tongues attached to the cable The lower part of the box was filled with paraffin-wax, and the upper portion with oil.

The skate consists of two metallic plates insulated from each other, and the circuit is completed from one plate to the other through the motors. The action of the skate is to wedge the contact-arms apart, thus forcing the brushes into contact with one of the tongues connected to the cable, completing the electrical circuit. In running in the reverse direction the contact-arms were deflected in the opposite direction and made contact with the other tongue Arcing was prevented by having the extreme ends of the contact-skate of insulating material, so that the switch was closed before the conducting portion of the skate reached the contact-arm, and the other insulated end of the skate held the switch closed for a short space after the metallic portion of the skate had passed.

A considerable length of this system was tested, about 1893, at Coney Island, New York, and was operated for some time with more or less success

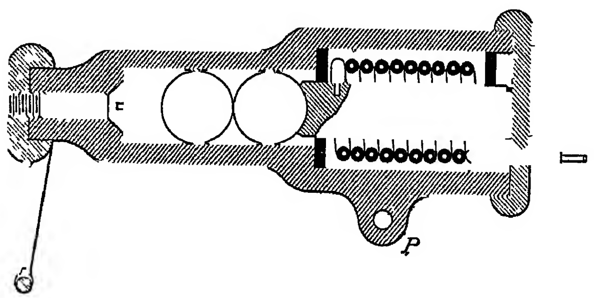


Fig 1050—Contact in Tilting Case Closed by Action of Balls

The proximity of the positive and negative contacts in a small conduit was not found as detrimental to the working as might have been expected A good deal of difficulty was experienced in keeping the water out of the switch-boxes, which resulted in frequent short circuits. The oil appeared to absorb the water and form a sort of emulsion which gave a great deal of trouble This indicates that oil, unless in hermetically-sealed cases, cannot be relied upon as an insulator in this class of work, as its chief value lies in enabling the switch mechanism to work smoothly. The inventors of this system claim to have designed boxes which overcome these defects, but it does not appear that they were ever put into actual service.

In the system shown in fig. 1050 the skate or collector wheel raises the sectional conductor T, turning the switch on the pivot P. This causes the balls shown to roll down on to the live contact. After the trolley has passed, the switch-box returns to its normal position by gravity, but as the current is being drawn from it, the magnetic coil holds the balls, which are of iron, in their position until the collector leaves the section, when they fall back to their original position by gravity There can be no possibility of arcing in this arrangement, for so long as any current is flowing through the switch the balls will be held in position, and they cannot fall until all the current in the wire ceases This arrangement, of using the coil in series with the sectional conductor for holding the switch closed, is used in many other systems to prevent arcing, and is a very effective method.

The Kingsland system is a very interesting member of this group, and the details appear to have been worked out with a great deal of skill and ingenuity. Fig. 1051 is a section of track through one of the switch-boxes, and gives a very fair idea of the general arrangement The contact-studs (fig. 1052), which consist of a cast-steel contact let into a granite or concrete block, are placed at distances of from 8 feet with a four-wheeled truck, up to about 20 feet for a car mounted on bogies. Each contact-stud is connected with a switch which is bolted to the base of the rail, and enclosed in a cast-iron street box, which box is provided with a removable cover through which the switch proper can be inspected or removed. Each switch-box is provided with a drain, which is connected to the drainage system of the town

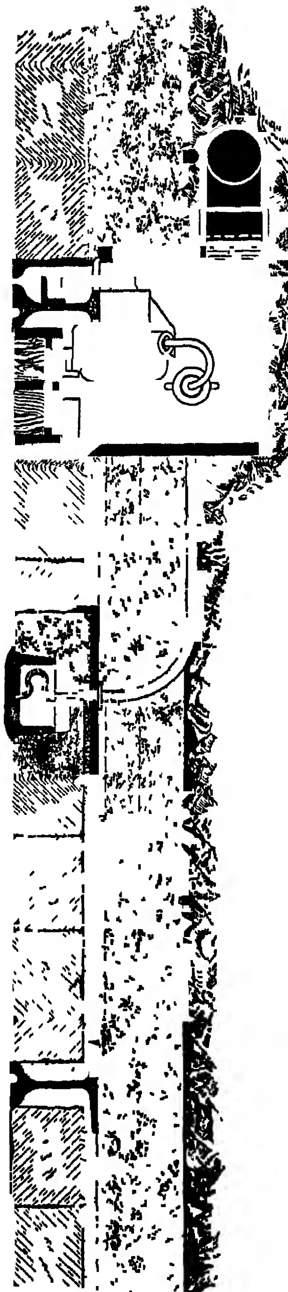


Fig 1051 —Kingsland System—Sectional View of Track

It will be noted that a small shallow conduit is required, which it is proposed to make by the use of an angle-iron close to the side of one of the running rails. The switch mechanism is enclosed in a circular water-tight iron casing, and is worked by a striker carried upon the car, depressing a vertical lever which is returned to its correct position by means of a spring This lever is shown in fig 1053, which also shows the method of preventing the lever from being shifted by unauthorized persons, through the slot A portion of the base of the rail is cut away to allow the lever to have free play The electrical arrangements of the system are extremely simple, and are shown in fig. 1054 They consist of a three-point commutating switch, which in its movements alternately connects and disconnects the main from the contact-stud Figs. 1055 and 1056 show this commutating switch. It consists of an outer case A, of insulating material, having two contacts D D, spaced 120° apart. The moving portion of the switch consists of an insulating ring C, provided with three brushes B B B, which are interconnected. These brushes are also spaced 120° apart. The switch mechanism is so arranged that each time the lever is moved by the striker the commutating switch is turned one-sixth of a revolution, and it will be noticed that no matter in which direction the commutating switch

is moved, to this extent it will alternately connect and disconnect the contacts D D. The current is never broken by the commutating switch, as the distance between the strikers, which are attached to the axle-box of the truck, is made slightly greater than the length of the contact-skate, consequently the switch is not opened until after the skate has left the contact-stud. If from any reason the advance switch failed to energize the advance contact, the arc would occur between the stud and the skate. This difference in length between the strikers and the skate also provides that the advance switch shall be closed before the skate touches the contact-stud This adds greatly to the certainty of the electrical connection being promptly established

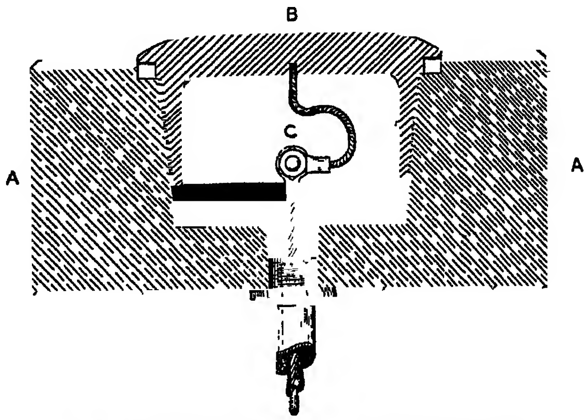


Fig 1052 —Kingsland System—Sectional View of Contact-Stud

The switch itself is a very ingenious piece of mechanism, and is shown in figs 1057 and 1058. The spindle 1, which carries the striker lever 2, also carries a crank 16 Attached to this crank, and actuated by it, are

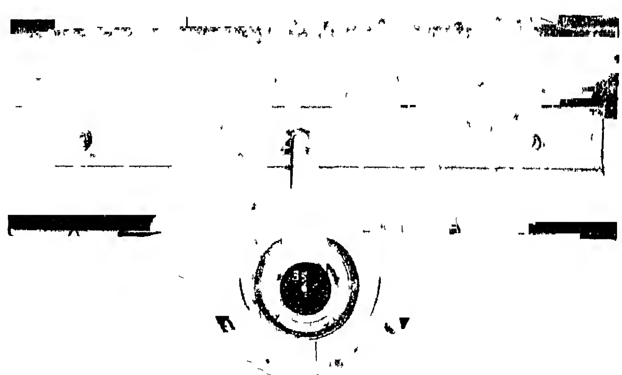


Fig 1053 – Kingsland System—Contact-Box attached to Rail

two pawls 17 and 18 (fig. 1058) A double ratchet-wheel 10 and 11, with six teeth sloping in opposite directions, is mounted on a sleeve 9. This sleeve is concentric with the spindle 1, and carries the rotating part of the commutating switch (see fig 1056) The casing of the switch is so designed that a portion of it, 3, forms a tube The outside of this tube is the bearing which carries the sleeve 9, ratchet-wheels, and commutating switch. The inside of this tube 3 carries one bearing of the spindle 1, and forms a recess for the coil spring 32. When the striker lever 2 is

shifted through one-sixth of a revolution by the striker, one of the pawls, 17 or 18 according to direction, engages with the double ratchet-wheel The teeth of this wheel are so proportioned that they move the commutating switch through the one-sixth of a revolution required, as above described When the striker has passed, the striker lever is returned to the vertical position by the action of spring 32. The pawl, 17 or 18, is

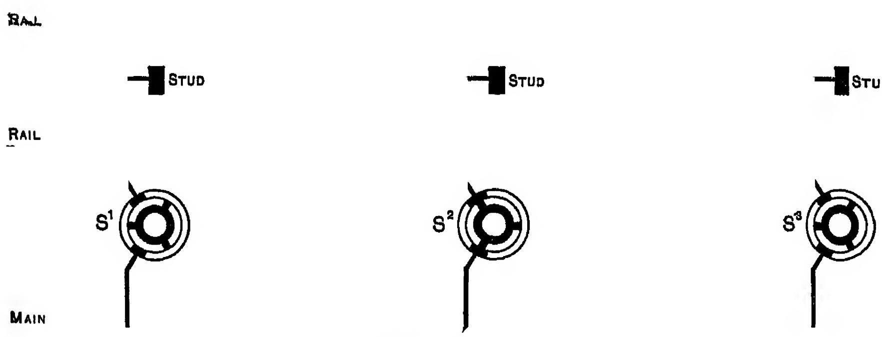


Fig 1054 —Kingsland System—Diagram of Electrical Connections

prevented from moving the commutating switch back to its original position by the crescent-shaped guide 21 The mechanism for returning the switch lever to the vertical position is ingenious The spring 32 is wound with square wire, and the distance between the coils is less than the thickness of the wire Consequently, should the spring break, it cannot screw into itself and will still work the lever

Fig 1055

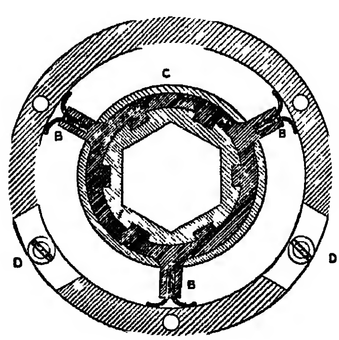


Fig 1056

27, 28, and 29 are three collars on the spindle 1 27 is rigidly attached to the spindle. 29 is free to slide on the spindle, and is prevented from rotating by guides 31, working in slots in the collar 29. 28 is free to rotate, and moves laterally on the spindle These collars have inclined faces, those of 28 having an inclination in opposite directions, so that in depressing lever 2 a screw action is set up between 27 and 28, which compresses the spring 32, and the spring acting in

the reverse manner returns lever 2 to its vertical position. If the lever 2 is depressed in the opposite direction the inclined face on the opposite side of 28 comes into action and compresses the spring in a similar manner. The spindle, lever, spring, and collars are shown in fig 1059 An arrangement is also provided for locking the double ratchet-wheel in its correct position at the completion of the downward movement of the striker lever The skate is shown in fig. 1060. It is a steel tube of special section, or an ordinary bar of T section may be used The end of the skate is reduced in section and slightly turned up, so that in striking the stud no shock or noise is caused. The striker is carried from the axle-box of the truck The striker arm is free to rotate on the vertical bolt which secures it to the axle-box of the truck. This enables it to accommodate itself to curves or lack of alignment between the slot and the groove of the rail The striker is secured to the arm by a spring knuckle-joint which, in event of its meeting an obstruction in the slot, would enable it to free itself without damage

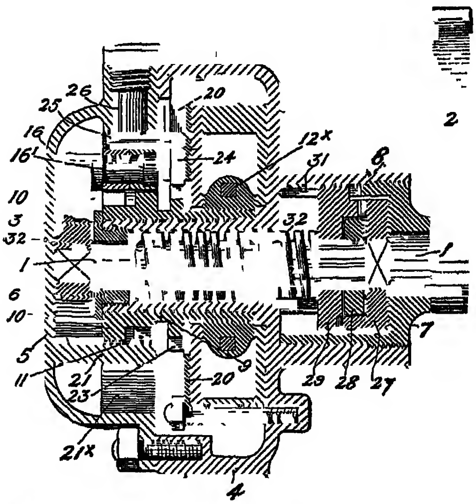


Fig 1057 —Kingsland System—Cross Section of Contact-Box

The electrical connections are made from the main feeder to the commutator, and from the commutator to the stud, by means of cables passing through stuffing-boxes 38 and 39 (fig 1058).

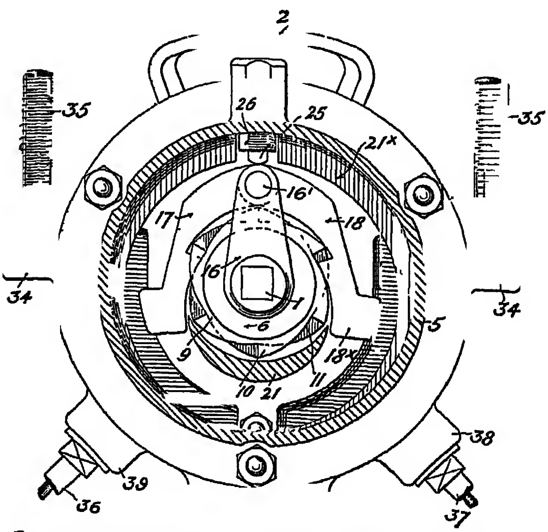


Fig 1058 —Kingsland System—Longitudinal Section of Contact-Box

This system has not been put into actual operation, but an experimental line has been working in Wolverhampton for some time. It is by far the best of any of the mechanical group of systems, but is open to many serious objections. Its high first cost, the large amount of metal exposed in the street, for there is the contact-stud, the slot, rail, and the cover of the street box; the small

conduit suggested, which presents considerable mechanical difficulty to prevent the slot from closing up, and introduces many expensive complications at points and crossings The switch, although a very pretty piece of mechanism, is decidedly complicated, and much difficulty will be experienced in preventing the water from getting inside of the switch with-

Fig 1059 — Kingsland System—Striker Lever and Actuating Springs and Cams

out making the bearing, where the spindle 1 passes through the side of the switch casing, so tight as to interfere with the action of the spring in returning the striker lever to its normal position If water works into the switch in sufficient quantities to flood the commutating switch—and a very small quantity of water will suffice for this—although it may not

Fig 1060 — Kingsland System—Contact-Skate

cause a short circuit or appreciable loss of power, it will leave the contact-stud alive The force of the spring which returns the striker lever 2 to its normal position works through an inefficient form of mechanism, and there would be considerable danger of this spring failing to move the striker lever after it had been depressed. The effect of this might be to leave the contact-stud permanently alive.

CHAPTER III

MAGNETIC SYSTEMS

The various systems of this class have been, on the whole, more successful in actual working than either of the other two classes. It is possible to reduce the switching devices to their fewest elements, and also to hermetically seal them.

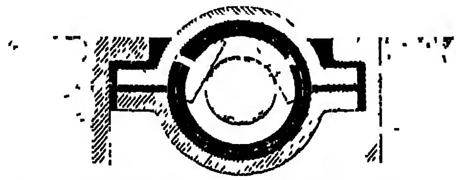


Fig 1061 —Rolling Ball held up by Magnetic Attraction

These systems, for simplicity and reliability, have much to recommend them They may be divided into the following groups.—

1 Those in which the contact between the feeder and the sectional conductor is either made by a movable closure, or one in which a flexible conductor follows the car with a wave motion.

2 Those in which a pair of magnet coils, or a pair at each end of the car, is used to operate the switch

3. Those in which the switch is actuated by a magnetic skate of nearly the length of the car, and magnetized by several pairs of electro-magnets, is used

4 Those in which a plain, solid, but rather heavy iron skate is employed both for the purpose of collector and for working the switches

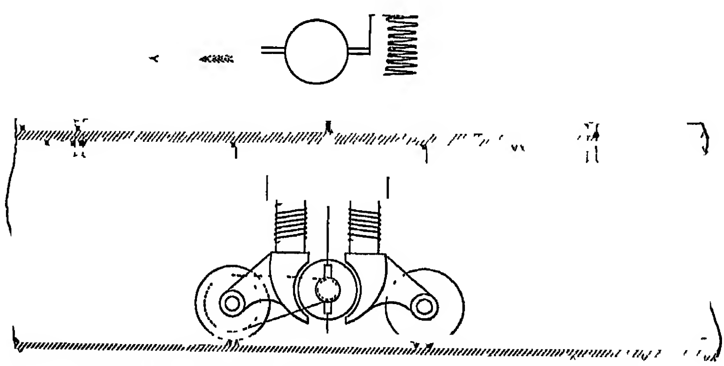


Fig 1062 —Motor runs in Conduit, follows Car, and keeps Circuit closed

(1) **Movable Closures.**—One of the simplest of these is shown in fig. 1061, in which a hollow steel ball is, by the action of the electromagnet carried on the car, drawn up so as to form a connection between the continuous and sectional conductors. As the car proceeds, the ball rolls along on the two conductors and completes the circuit to the several rails of the sectional conductor in turn. There is no difficulty in making the ball follow the car so long as the magnet remains energized, but should the magnet fail from any cause, even momentarily, the ball will drop, and will either roll away from the car, or the car will coast on and leave the

ball stationary, in which case it would be almost impossible to find the ball and re-establish the circuit.

A modification of this has been suggested in which the ball is replaced by an electromagnet running on small wheels. The current taken by the car passes through this coil and increases the magnetic attraction between the moving closure and the magnet on the car. Numerous devices have been proposed in connection with systems of this kind which would, in event of the failure of the magnetizing current, act as automatic brakes, and retain the moving closure stationary at the point where the magnetism failed. These can be made quite successful in themselves, but only meet half the difficulty, as they do not assist in locating the lost closure, and do not prevent the car from coasting away from it.

Fig. 1062 shows another system of this group which is quite interesting. The moving closure consist of a small series motor running on rails. The motor has two field coils so wound that when one is in service it tends to run the motor one way and the other coil acts in the other direction. One brush on the commutator makes contact with the continuous conductor, the other with the centre point between the field coils. The outer end of each field coil is connected to a travelling contact running on the under side of the sectional conductor. The travelling closure takes up the position shown in the cut. Should the car slow down the tendency of the closure is to run ahead, but as soon as the leading contact reaches the advance section the current passes through the rear coil, which reverses the direction of the motor and brings it back under the car. After the current, however, is completely shut off on the car, there is nothing to prevent either the trolley or the car from coasting ahead. This system is perhaps more strictly electromagnetic than magnetic, but seems naturally grouped with the moving closures.

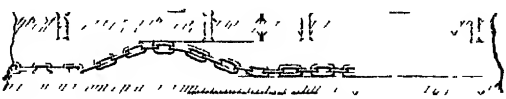


Fig. 1063.—Chain Conductor lifted by Magnet on Car.

In fig. 1063 a continuous conductor is placed at the bottom of a small sealed conduit, of which the sectional conductor forms the top, and upon which runs the collecting device. In the conduit lies an iron chain or other flexible iron conductor which is attracted by the magnet carried on the car, and thus forms the connection between the continuous and sectional conductors.

But the contact made by this means is somewhat uncertain, and the flexible conductor is liable to become bunched and leave portions of the sectional conductor alive. A modification of these systems has been proposed by placing the sectional and continuous conductors close together at the top of a small conduit, and partly filling the lower portion with iron-filings, which are attracted by the magnet on the car and form contact between the two conductors. However, the residual magnetism in the iron-filings is liable to keep the sectional conductor alive after the car has passed, and the iron-filings have a great tendency to become

bunched. In a short time also the filings become rusty and fail to convey the current.

(2) **Single Magnets or Magnets at Each End of Car.**—Fig 1064 shows one of the simplest of this group of systems. A small conduit is provided, at the bottom of which is the continuous conductor, and the top is connected with the sectional conductor. A number of short arms are hinged and connected to the continuous conductor, which normally lie in the bottom of the conduit. Under the action of the magnet carried on the car

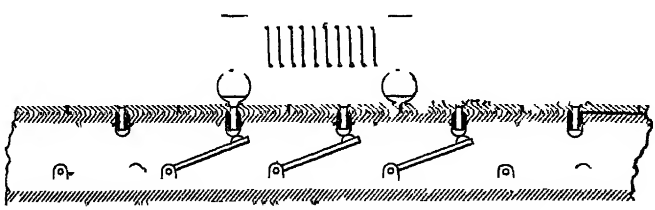


Fig 1064 —Pivoted Contact-Arms lifted by Magnet on Car

they are raised, completing the circuit between the continuous and sectional conductors, and fall by gravity after the car has passed. The number of these devices must be very considerable, and the provision for breaking an arc, should one occur, is not very satisfactory

Fig 1065 shows a system in which a sectional rail is used This is supposed, by the action of the magnet on the car, to be magnetized for its entire length, which serves to retain the contact devices in position

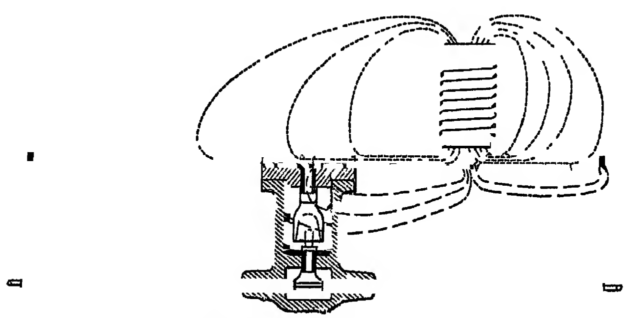


Fig 1065 —Magnetized Sectional Rail holds up Contact

while the car is over that particular section of the conductor It is obvious that any desired form of switching device can be used with this, but the one shown is on the principle of an iron armature floating in mercury, which will be described later on

Fig 1066 illustrates a somewhat unique arrangement In this case there are three electromagnets carried on the car, but instead of being stationary they are attached to a chain running over sprocket-wheels at each end of the car. One of these movable magnets, when on the lower side of the chain, touches a contact-stud, which may contain any

suitable form of mechanism The force of magnetic attraction holds the coil in place, while the chain running over the sprocket-wheels brings the next magnet in contact with the advance stud, and at the same withdraws the rear magnet from its contact-stud This arrangement av the rubbing contact between the collector-skate and the stud, but intro duces additional complications which probably prove more objectionable

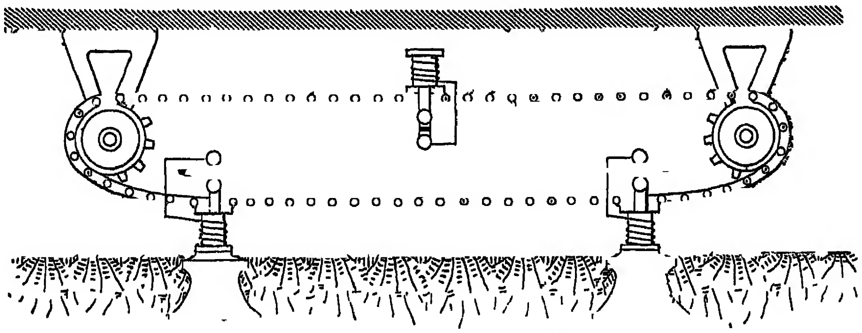


Fig 1066 —Chain Current Collector carrying Magnet Coils

In fig 1067 the magnet on the front of the car attracts the armature 20, which is connected to a pawl, the movement of which actuates a ratchet-wheel that switches the current on to the sectional conductor or contact-stud Another magnet coil is provided at the rear of the car, which in its turn attracts the armature and moves the ratchet-wheel, thus cutting the section of the sectional rail out of circuit

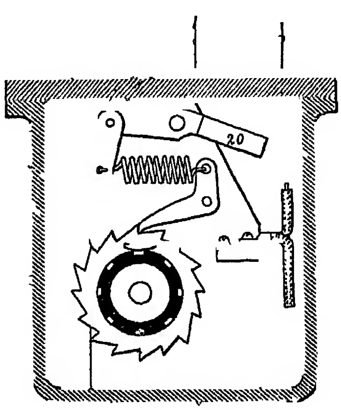


Fig 1067 —Magnet on Car attracts Armature and moves Ratchet-Wheel, switching Current On and Off

Fig 1068 shows a similar device Two armatures, 9 and 10, are mounted on a tilting frame which is free to move on the pivot 8. This movement causes the arm 12 to open and close the switch 14 The magnet on the front of the car attracts the thin plate 29, unlatches the hook 31 from the lug 33, the lever carrying the armatures 9 and 10 is thus set free, and under the action of the magnet on armature 9 will close the switch 14 The magnet on the rear of the car attracts armature 10, opening the circuit and securely latching the lever into place. This device is a very good one of its kind, but it substitutes for the positive action of gravity in opening the switch, magnetic action in which there is a chance of failure.

The system shown in fig. 1069 is interesting, but somewhat too complicated for practical purposes. A magnet is hung from a pivot at the front end of the car, which attracts and lifts a specially-shaped casing, which is also free to move on a pivot. Within the case is a metal

ball which, upon the case being tilted, rolls down and makes contact at one end of the casing, before the casing can fall back into its original position it is caught by the skate on the car and held in its raised position until the car has passed, when it falls by gravity. A modification of this device has been proposed whereby the casing, instead of being raised by magnetic attraction, is lifted by the action of a plough which travels in the groove of the rail in advance of the wheel. The casing is pivoted at right angles to the track, and is raised by the plough sufficiently for it to clear the wheel

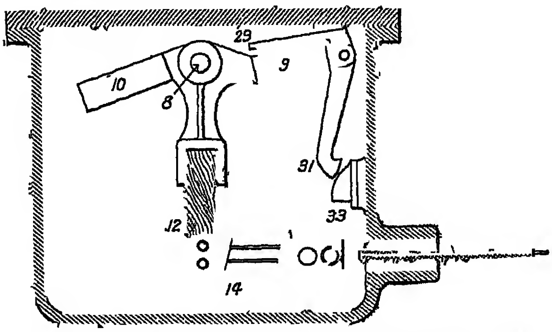


Fig 1068 —Magnet on Front Car attracts Tilting Lever and closes Switch Magnet on Rear of Car opens Switch

Fig. 1070 illustrates a system in which a large magnet energizes the rails, which in their turn, through suitable magnetic conductors, actuate a polarized armature, which is free to move on a pivot, thus closing

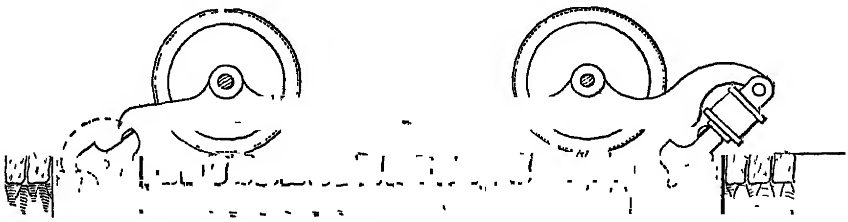


Fig 1069 —Swinging Magnet on Car lifts Tilting Casing, which is held up by Collector Skate on Truck Frame

the circuit between the continuous and sectional conductors A similar magnet is carried at the rear of the car, which acts in the reverse direction and opens the circuit There does not seem to be any particular

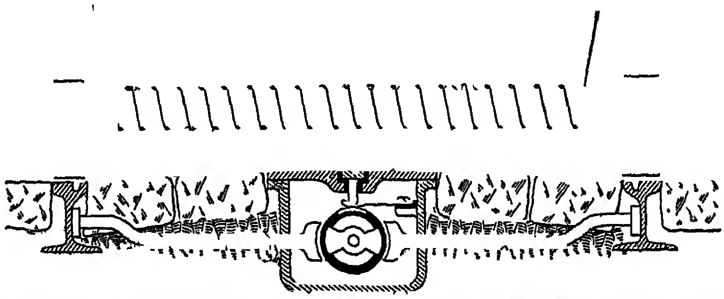


Fig 1070 —Large Magnet across Car rotates Armature and closes Switch. Magnet on Rear of Car opens same

object in providing for such a long magnetic circuit. The same result could be obtained by much smaller magnets

In the system shown in fig. 1071 the magnet on the front of the car

draws an armature into contact with the stud, thereby completing the circuit between the sectional and continuous conductors. All current to the car passes through a magnetic coil on the armature, which consequently keeps the circuit closed as long as any current is flowing to the car. When the car has passed and the current ceases the armature falls back by gravity. This system requires a magnet at each end of the car, in order that the car may run in both directions. The magnet on the rear of the car is so arranged that this polarity can be reversed, so that it will assist the armature in disengaging itself as the car leaves the section. A large number of different forms of switch may be worked on this principle.

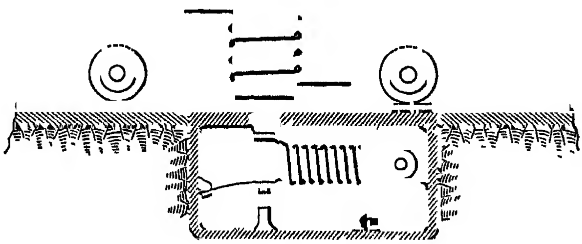


Fig. 1071.—Magnet on Car lifts Magnet in Conduit, which has Coils in Series with Car

The connection of the magnet coil on the closure in series with the car is very efficient in preventing arcing, but has this disadvantage, that any leakage of current between the sectional conductor and the rail has a tendency to hold the switch closed and leave the surface contact alive.

(3) **Magnetic Skate.**—Of this group the Diatto system is the best known, which, with modifications in detail introduced by other inventors, has in actual practice been the most successful of all surface-contact systems.

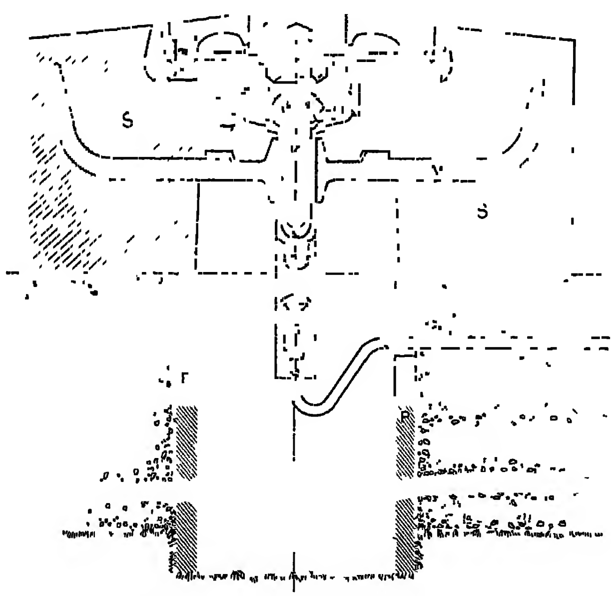


Fig. 1072.—Section of Diatto Contact-Stud

The Diatto system, in its earlier form, consisted of a contact-stud projecting slightly above the paving, and a cup of insulating material partially filled with mercury, which was connected to the main feeder. Floating in the mercury was an iron or steel ball, which ball was raised by magnets carried on the car to form a contact with the under side of the contact-stud. The ball was so designed that nearly all of its weight

was borne by the mercury, leaving very little for the magnet to lift, and when in contact with the plate nearly all of its weight was available for the gravity release, the mercury forming a frictionless contact.

A detailed description of the later form of the system will be of interest. A sectional view of the contact-stud and switching device is shown in

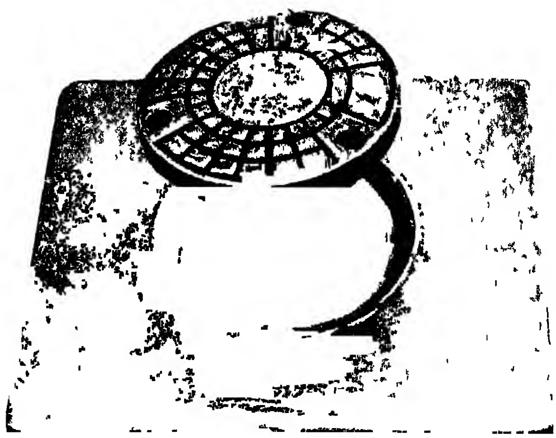


Fig 1073 —Diatto System—Contact-Stud and Block-Stud raised

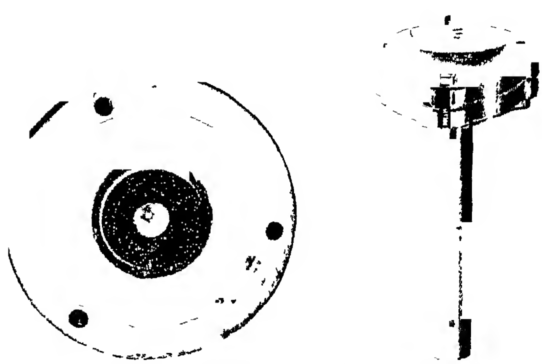


Fig 1074 —Diatto System—Plan and Elevation of Switch-Box

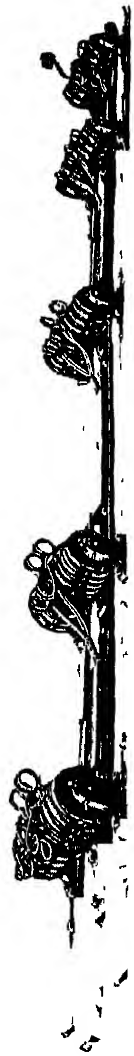


Fig 1075 —Diatto System—Electromagnetic Contact-Skate

fig 1072. The body of the contact-block S is of asphalt, or on the latter sections of hard vitrified clay, hollowed out for the reception of the switch mechanism and contact with the main feeder. A recess below the contact-box is made by the use of an earthenware pipe P, which affords room for making the connection. The contact-box and pipe are laid on the concrete foundation of the tramway, and the whole space

made water-tight by the use of asphalt A brass ring B is embedded in the contact-block S. Into this ring a disc A of non-magnetic metal is inserted. In the centre of this disc is secured a plug C of soft iron A perspective view of the box with the cover raised is shown in fig 1073 To this soft-iron centre-piece is secured by means of a thread a hermetically-sealed box (fig. 1074), with a tube-like projection Y from its lower side, which contains the switch contact proper. In the top of this box is a metallic plug I, which is provided with a carbon cap D having a conical recess The plug I (fig. 1072) is screwed into the soft-iron button C, and holds the sealed cup in place The tubular portion of this cup, which is made of ebonite, is filled with mercury, and in it floats the iron pin K, which is provided with a conical carbon head H Into the bottom of this tube is screwed a copper plug N, which is provided with a tail-piece of the same metal, which passes into a recess R in the lower end of the tail of the cup In this recess R is a small ebonite cup O filled with mercury, which is in metallic connection with the feed-wire Q The tail of the plug N dips in the mercury in the cup O, and thus forms a metallic connection between the feeder and the mercury in the main cup. The recess R acts on the diving-bell principle, and would prevent moisture from reaching this contact even if the pipe P were filled with water. The piece M is of cast-iron of great magnetic permeability. It is embedded in the block S, and carries the cast-iron cross-piece L, which in turn supports the tail-piece of the hermetically-sealed cup.

Fig 1076 —Diatto System—Contact-Skate in position under Car

The contact-skate is shown in figs. 1075 and 1076. It is composed of three parallel strips of iron, and provided with ten electromagnet coils arranged in pairs, so that the two outside skates are of one polarity, and the centre skate of the opposite. The action of the switch is as follows —

The lines of force from the outside skates or north poles pass through the piece M, the pin K, the button C, to the centre skate or south pole of the respective magnets. The magnetic attraction thus draws the pin K upward and presses the carbon plates D and H into contact The current passes through the magnetic coils, thus increasing their magnetism and the contact pressure between the carbon discs, in direct proportion to the current transmitted The centre skate, which alone makes electric contact with the button C, is turned up slightly at the ends, so that it breaks the electric connection with the stud before the magnetic circuit is broken. This prevents an arc taking place in the sealed box, for any tendency to arc, owing to the failure of the advance contact to arc, would occur between the stud and the shoe.

It will be seen from the construction of the switch that there is little possibility of the switch failing to open. The contact being of carbon,

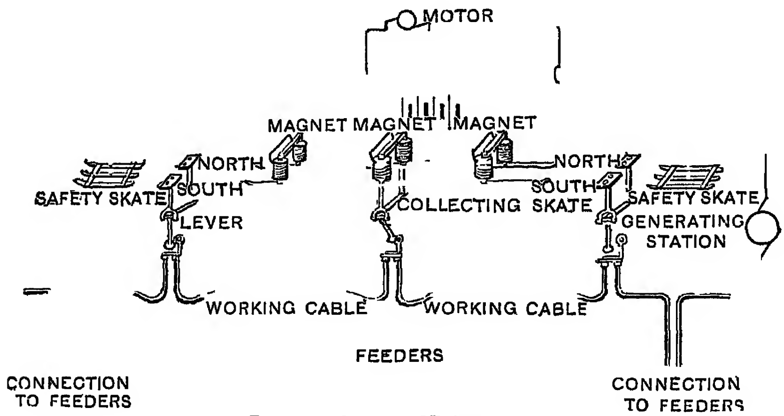


Fig 1077 —Diagram of Dolter System

there would be no tendency to weld in transmitting a heavy current, and no tendency to stick from residual magnetism. The magnet coils on the skates are provided with two windings, one in series with the motors, and the other in series with a small storage battery carried on the car This storage battery is used for picking up the first contact After the car is running it may be cut out and the switches worked entirely from the main current Each car is provided with a secondary skate or brush, which comes in contact with the stud after the main skate has left it, and if it is still alive will form a short circuit, and thus blow the fuse on the car

This system has been used to a considerable extent in France—at Tours, Lorient, and Paris About fifty miles in all have been constructed, and in some places have given satisfaction

The most serious difficulty experienced has been from the mercury forming a film over the inside of the cup and keeping the contacts alive, but this could be avoided by omitting the mercury, as has been done by other designers Some difficulty appears to have been experienced from arcing in the switch-boxes, but this has been eliminated on the most

recently-installed section of this system by the use of the magnetic blow-out, and improved methods of securing alignment between the stud and rail have materially increased the smoothness of working.

The Dolter system is a modification of the Diatto system, and has been worked in Paris on a short line with a considerable degree of success. The system is shown in diagram in fig 1077, from which the working of the system can be readily traced. The contact-switch is clearly shown in fig 1078. It consists of a cylindrical box, made of an insulating waterproof material, and hermetically sealed Into the lower part of this box are laid the connections from the main feeder, which are permanently connected to a carbon contact located at one side of the cylindrical chamber. The contact-lever itself is L-shaped, very loosely pivoted at the top of the box, and falls by gravity in a vertical position away from the carbon contact at the side of the box

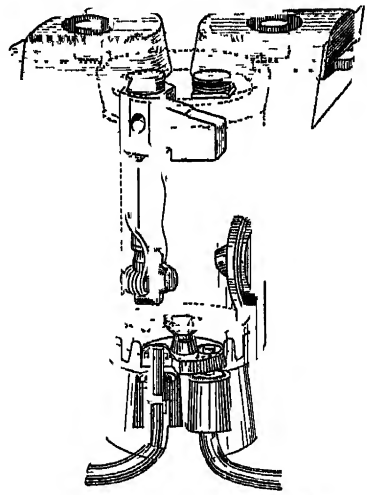


Fig 1078 —Dolter Contact Stud

The action of the system is clearly shown in figs 1079 and 1080, which are partly diagrammatic. The contact-studs are of cast-iron, B B, and are embedded in a non-magnetic block, and separated from each other by a non-magnetic material *b* The whole contact stud and box rests in a manganese steel chair F, embedded in an asphalt block A A. The contact-

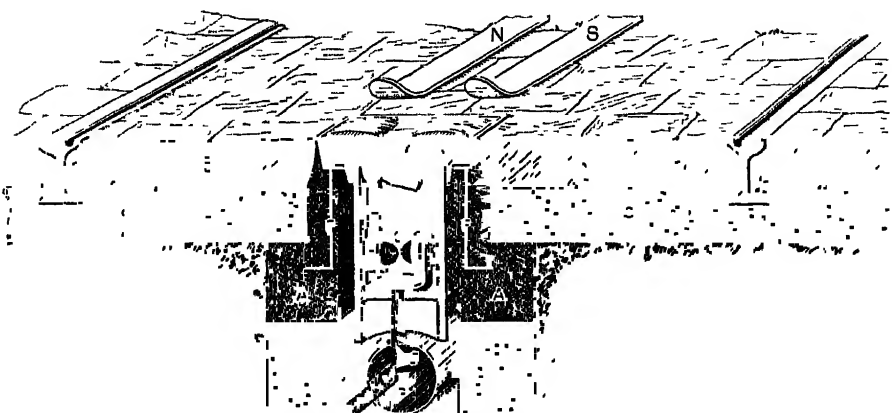


Fig 1079.—Dolter System—Skate approaching Stud, Circuit Open at Automatic Switch

skate consists of two long magnets energized by seven magnet coils placed at suitable intervals. Both these contact-skates are alive, and aid in collecting the current. Upon their coming in contact with blocks B B, a magnetic circuit is established from the blocks B B and contact lever L,

which is drawn up into the position shown in fig. 1080, making contact with the carbon contact above referred to and one of the blocks B Upon the contact-skate having passed the stud, the lever L falls back into its original position by gravity. The whole box can be lifted clear for inspection or replacement by raising the two catches shown in dotted lines on fig 1078. Sufficient slack is left in the cable to allow the whole box to be lifted clear of the hole, when the upper part of the box can be unscrewed from the lower as indicated in dotted lines on fig. 1078

The system is quite simple and the details appear fairly well worked out, but no attempt has been made to energize the stud before being struck by the skate, and no arrangement provided for ensuring that should it be necessary to break an arc when the skate is leaving the stud, that it should break on the surface of the street and not in the box,

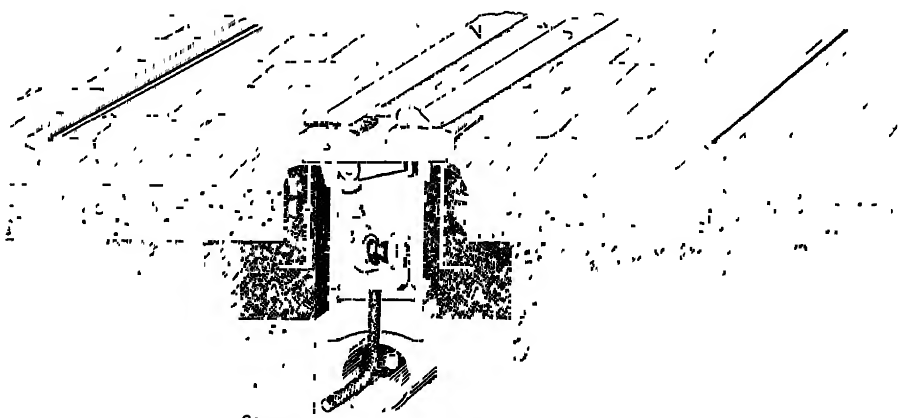


Fig 1080—Dolter System—Skate over Stud, Circuit Closed at Automatic Switch

although the turned-up ends of the skate would accomplish this to some extent A safety skate is provided which, in event of the contact-lever L sticking in position and leaving the stud alive, would form a short circuit and blow a fuse in the contact-box This does not seem a good place for a short circuit to be broken by the blowing of a fuse, and it necessitates the removal of the contact-box to replace the fuse It would also be somewhat difficult to tell when the fuse had been blown, and the stud being dead, it would be necessary to break the current at the adjacent stud each time a car passed over it, which might cause serious damage before it was discovered It will be noted that both skates are in electric and magnetic contact with the stud This practice doubles the wear on the skates, and doubles the area exposed to surface leakage

The Diatto and Dolter systems, as will be noticed, are remarkably simple The number of moving parts is reduced to a minimum The contact-studs are placed in the centre of the track as far as possible from the rails, and also where possible they are raised slightly above the head of the rail, which facilitates drainage The stud does not project very

much above the street, not exceeding $\frac{3}{4}$ inch, and the area of exposed metal in the street is small. The switch is opened by a simple gravity action, and it seems difficult to conceive of the armature sticking in position. As the contacts are made of carbon, there is no danger of an imperfect contact or excessive current heating them so as to form a partial weld, as might occur with metallic contacts.

It will be noted that no arrangements are made for dealing with any arc that may be formed in the insulated cup of the switch itself, except in the latest section of the Diatto, and it will also be seen that this switch is not capable of breaking large currents with safety, as the space is so confined that heavy sparking would soon destroy the switch. Of course under normal conditions no sparking should take place inside the switch, for if the advance contact fails to make connection the break should take place between the shoe and the contact-stud

The most serious drawback of these systems is the long, heavy cumbersome magnetic skate which, as above stated, consists of from five to seven magnet yokes, having in all twelve or fourteen coils, some of them wound partially with fine wire These are carried from the truck frame so that they are supported with a considerable degree of rigidity, and consequently subjected to a great amount of vibration, extremely liable to cause fine wires to break Should in any way one or more of these coils become defective, that particular magnet would release the contact-switch and cause an arc, and the next one would pick it up so that the car would not be stopped, but dangerous arcing would take place in each of the contact-boxes This might go on for some time before it was discovered, perhaps as much as a day or two, and while so running that particular car would be damaging every switch that it ran over

It is necessary to keep the magnet coils energized during the whole time the car is in service, and this in the course of a year would represent the waste of a very considerable amount of power The extra weight carried is considerable, and is nearly all a dead weight on the axle, which would tend to increase the wear and tear on the permanent way and the wheels, and would increase the amount of power required to run the car, probably by about 5 per cent. The friction between the skate and stud would also require an appreciable amount of power to overcome, as the magnetic attraction between the skate and stud tends to increase the pressure due to the weight of the skate

If the short-circuiting devices should come into action, it would throw a considerable portion of the line out of use, and it might be necessary to inspect each switch-box in that group before the traffic could be started again. There is also danger of this coming into use unintentionally, particularly when the car is running at high speed. The opening of the contact-switch, working entirely by gravity, must take an appreciable time to commence to act, and it is quite possible that the trailing chains referred to would cause a short circuit before the contact-piece had time to fall. A car running at 15 miles per hour moves 22 feet per second, and as these short-circuiting chains are about 4 feet from the end of the skate, the contact-switch has only about one-fifth of a second in which to

break contact. It will readily be seen that any sluggishness in action on the part of the switch would cause the short circuit, which would disable a considerable portion of the line. The weight of the moving parts of the switch is considerable, and their impact in closing is sufficient to damage the carbon contacts by chipping, especially with the conical carbons of the Diatto system.

There will be loss of power in these systems from the following causes.—

Leakage to earth
Additional weight of skate
Friction of skate
Power used in energizing skate.
Resistance in carbon pressure contacts in switches

Amounting in the whole to an increase of from 20 to 25 per cent above that required by the trolley system

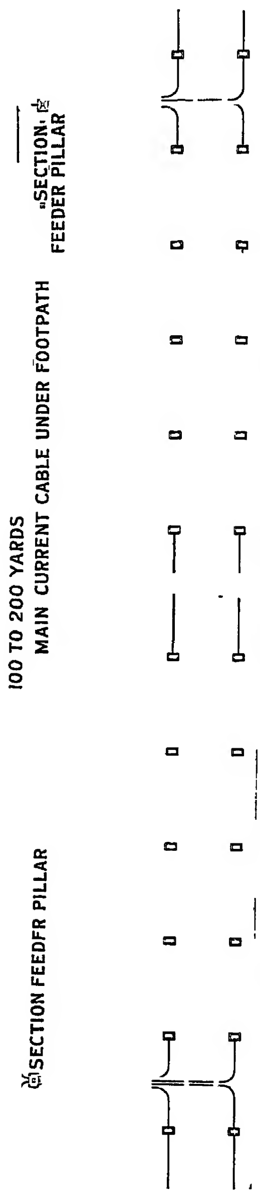


Fig 1081 —Lorain System —Diagram of Connections between Contact-Boxes and Main-Current Cable

The Lorain system is of particular interest as being one of the few that have been put into actual service, and the only one which has been so used in England It is not unlike the Diatto system in principle, but a flat flexible strip of copper replaces the mercury, thus avoiding all difficulty from that source The mechanical and electrical details have been worked out with exceptional care, and considerable judgement has been shown in selecting the most suitable materials for insulation and general purposes The contact-boxes are placed between the rails at distances of about 10 feet, varying somewhat with the type of car used. A convenient number of these are connected to a distributing main which corresponds to the trolley wire, and is carried in a suitable duct with a Y-branch pipe at each contact-box The distributing main is then carried to a switch pillar located on the footpath, where the connection is made to the main feeder. Any convenient number of groups can be run into one section-feeder pillar These pillars are usually placed a couple of hundred yards apart. This is shown diagrammatically in fig. 1081. The contact-box is shown in figs. 1082, 1083, 1084, 1085, 1086, and it will be seen that this is as simple as it is possible to make a switch of this description It has but two moving parts, one of which is a flexible connection. The base of the contact-box W (fig 1082, but shown more clearly in fig.

1086) is composed of reconstructed granite—that is, granite which has been reduced to powder, pressed into the desired shape, and subjected to a temperature of about 3000° F. The result is an insulating material of great strength and durability, entirely non-absorbent, acid-proof, and not affected by heat or cold—in fact, a material which is particularly suited for this class of work. Into this insulating block is fitted and secured by bolts a metallic cover L L′ (fig 1082), 12¾ by 6¾ inches To this cover is fastened the mechanism of the switch, so that by removing the two nuts shown the entire switch can be removed for examination or replacement

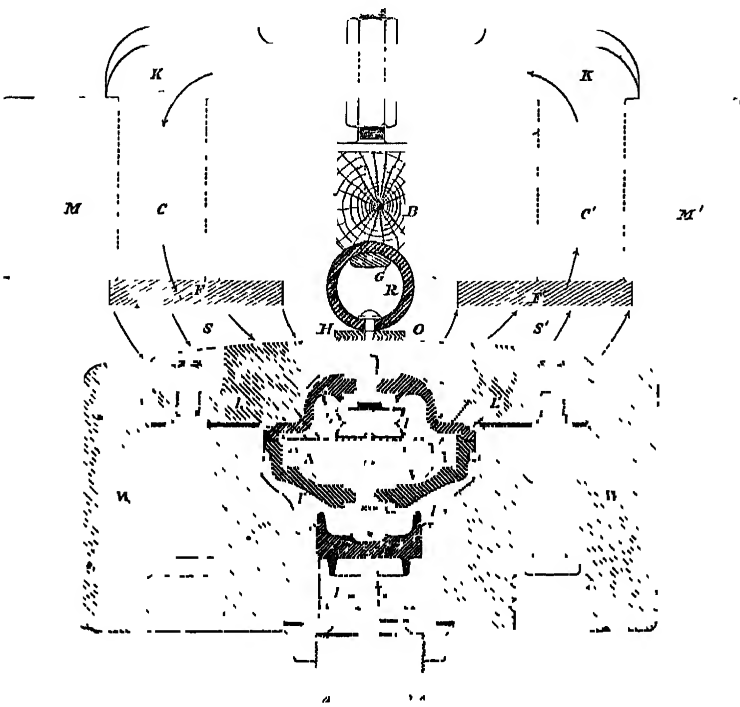


Fig 1082 —Section of Contact-Box, Contact-Shoe, and Magnet System on Car

with a good deal of ease The cover of the contact-box consists of three sections, two of which (L L′) are of iron, and the third (the centre-piece O) of special non-magnetic steel. This is extremely hard and tough, and particularly well adapted to resist the wear of the collecting shoe H This part of the cover is the highest, and is about ¾ inch above the paving of the roadway. In the switch between the cover and the base is secured an insulating cup V V′, which contains the switch contact. This cup is made in two sections, and is hermetically sealed by means of a gasket and an annular screw-ring. The cup is of a moulded insulation, similar to that employed for overhead trolley-wire insulators, but of improved quality, and has brass screw terminals moulded into the top and bottom. The top terminal is screwed into the steel cover O, and holds the cup in position. The bottom terminal is a spring clip forced over solid contacts

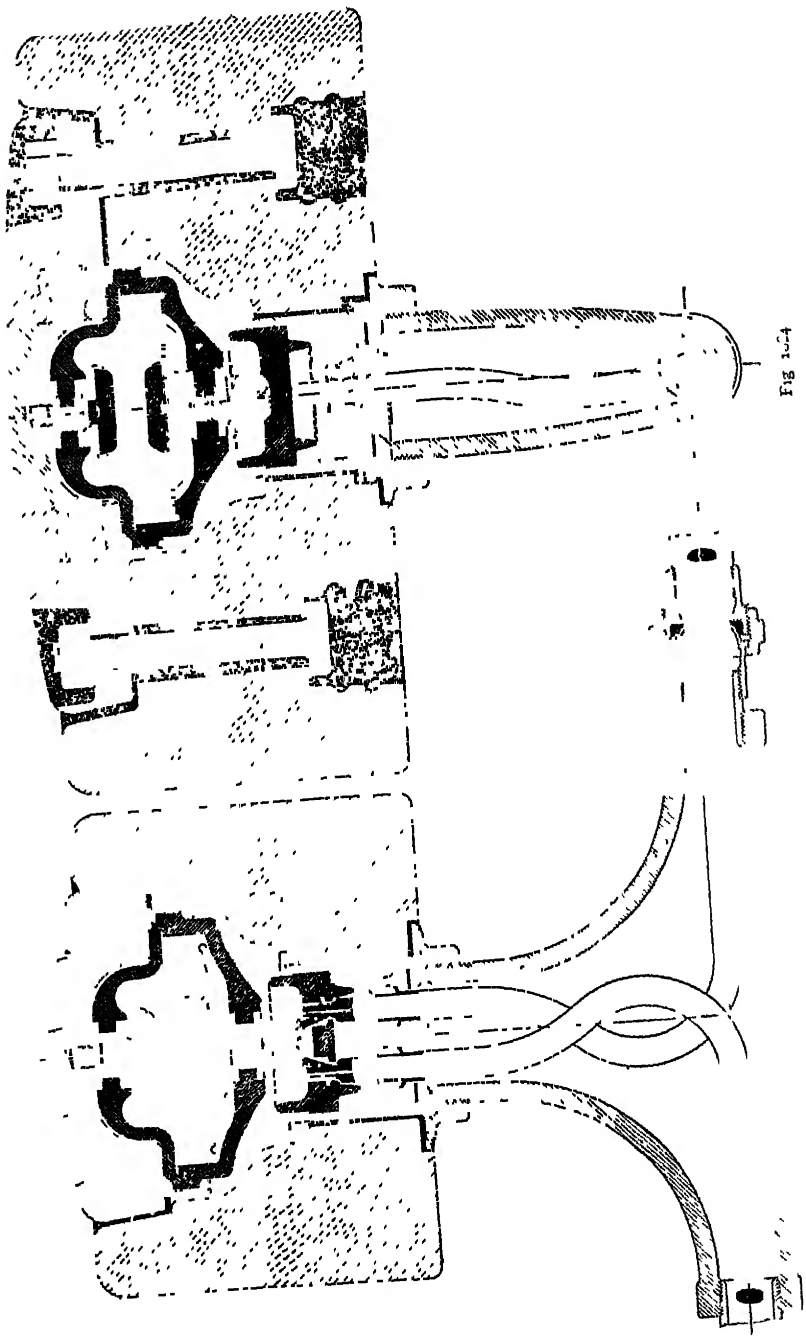


Fig. 1033 Lorain System.—Longitudinal and Transverse Sections of Contact-Box Fig. 1034

which are connected to the distributing main, and the whole is held in place by the main bolts holding down the cover.

Into the circular hole in the base of the contact-block is fitted a brass gland, which is held in place by an annular screw-ring. This gland is screwed into the top of the Y-branch pipe above referred to, and has a disc fitted in the bottom, which is provided with two stuffing-boxes, through which are passed the ends of the distributing main, and the stuffing-boxes are packed tight on the lead sheathing. In the top portion of the gland is placed a disc of insulating material carrying the spring contacts above referred to, and also screw contacts for connecting to the distributing main. The entire space around the outside of the cup and inside of the gland T T T is filled with a heavy insulating oil having a greater specific gravity than water By this means water is effectually prevented from reaching the live portions of the circuit Another method, which is not shown, but now considered preferable, is to lay the cables on the solid system, bringing the ends up into the bottom of the switch-block, and filling the space about them with bitumen

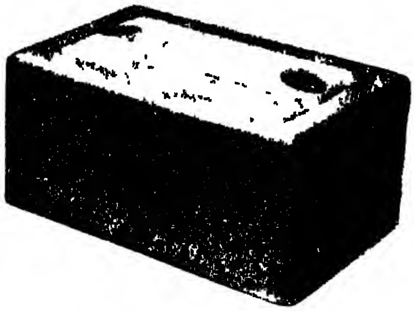


Fig 1085 —Contact-Box (Lorain system)

The switch itself consists of a soft-iron plate A, $4\frac{3}{4}$ inches by 2 inches by $\frac{1}{16}$ inch, weighing but $3\frac{1}{2}$ ounces To this is secured a carbon contact

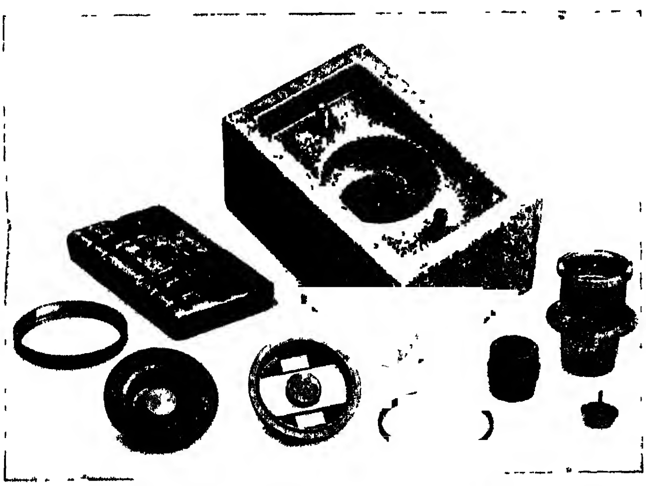


Fig 1086.—Parts of Contact-Box (Lorain system)

disc E about 2 inches in diameter. A similar carbon disc contact D is secured to the brass terminal moulded into the top of the cup A hard-rolled copper ribbon, $1\frac{1}{2}$ inch wide, folded upon itself in Z shape, as shown in fig. 1083, forms the electrical connection between the armature A and the terminal in the bottom of the insulated cup, which is in turn connected to the distributing main The armature normally lies in the position A′ A′

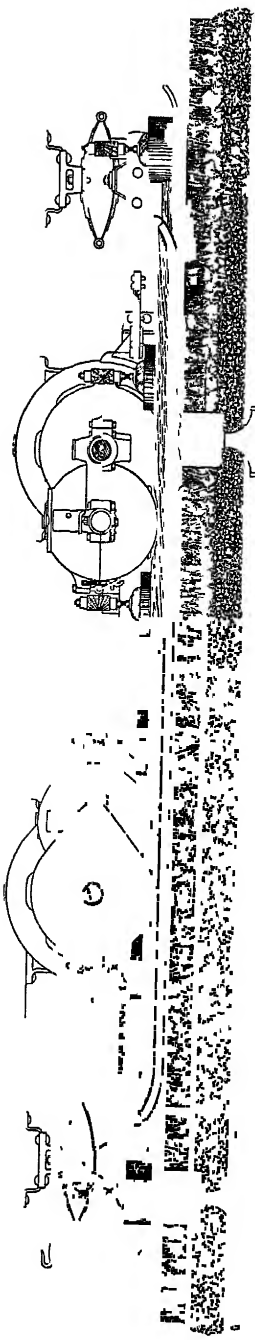


Fig 1087.—Lorain System—Longitudinal Section of Track and Motor Truck

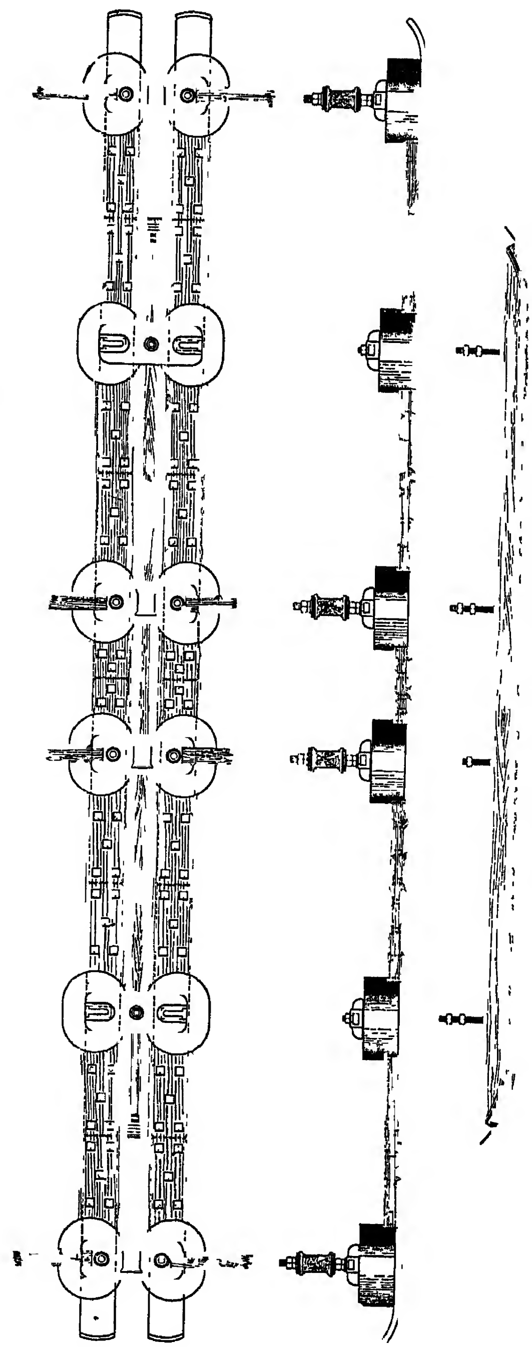


Fig 1088.—Lorain System—Plan and Sectional Elevation of Magnets and Shoe

indicated in dotted lines in fig 1082, and shown clearly in fig 1084. The switch is actuated by an electromagnet carried upon the car, which is ener-

gized by the coils M M′. The lines of force pass through the yoke K K, the cores C C′, the pole-pieces F F′, the spaces S S′, the cover of the contact-box L L′. The armature A A is thus in a strong magnetic field, and is attracted upward, its carbon disc E forming contact with the carbon disc D. The electric circuit is thus established from the distributing main to the contact-stud O. The current collector is about 12 feet long, or of sufficient length to a little more than bridge the distance between two studs. It is composed of a non-magnetic plate H, a piece of heavy rubber or linen hose R, and a wooden support B. This latter is secured to the yokes of the magnets by bolts so as to be adjustable.

As the contact between the discs D and E is entirely dependent on the pull of the magnet carried on the car, several of these magnets are required, six or more according to the length of the car. The pole-pieces of each magnet are provided with strips of iron about 2 feet 6 inches in length and 5 or 6 inches in width, placed longitudinally with the car. The extended pole-pieces of the six magnets nearly touch each other and are securely bolted to wooden distance-pieces, thus forming two continuous and parallel electric magnets. So that the magnetic attraction on the armature A A is practically constant during the whole time that it is under the skate. Details of the magnets and contact-shoe are shown in figs. 1087 and 1088. These parallel magnets are made somewhat longer than the collecting-skate, the result of which is that the stud is energized before the skate comes in contact with it. This adds greatly to the certainty of the contact being established before it has been broken on the preceding contact. The contact-skate also breaks contact with the stud before the stud passes out of the influence of the magnet. Consequently, if any arcing takes place it occurs between the stud and the skate, and not in the contact-boxes. The magnet coils are provided with two windings, a series and shunt. The shunt winding is connected across the main circuit and requires about 1 ampere of current, and is always in use while the car is running. The series coils have a resistance of .175 ohm and are connected in series with the motors, thus giving a contact pressure on the carbon discs D and E proportional to the amount of current transmitted.

The small storage battery is provided for picking up the first switch on starting. Arrangements are made for charging this battery without removing it from the car. A diagram of the car wiring is shown in fig. 1089. It will be noted that it is so arranged that the car can be run either from the overhead trolley or by the surface-contact system by the simple change of a switch. The ease with which this can be done is a distinct advantage of this system. An earthing device is provided whereby any stud left alive after leaving the magnets is short-circuited to earth, blowing the fuse or safety device in the switch pillar. This is similar to that employed in the Diatto system. The total weight of the magnets, collecting devices, storage battery, &c., is about 2000 lbs., equivalent to about 12 per cent of the weight of the car.

The line as installed at Wolverhampton appears to have worked very well, and has been in service rather more than a year. About 11 miles are now in operation.

Some damage has been caused to the switch-boxes by short circuits, owing chiefly to scrap-metal having been mischievously placed on the track at points and crossings where the skate is obliged to cross the running rail, but it is claimed that this difficulty has now been overcome. A small number of the studs show, when tested, traces of leakage, caused by the carbon dust which is thrown off from the slight arcing caused chiefly by the leakage current; and although this leakage may give quite a high voltmeter reading, the amount of current that this film of carbon dust can transmit is so small that there is no real danger from it. Great care has been exercised to minimize the disadvantages of the magnetic skate. The wearing portion is easily and cheaply renewed, and the pressure of the skate on the stud is entirely independent of the weight of the magnets on

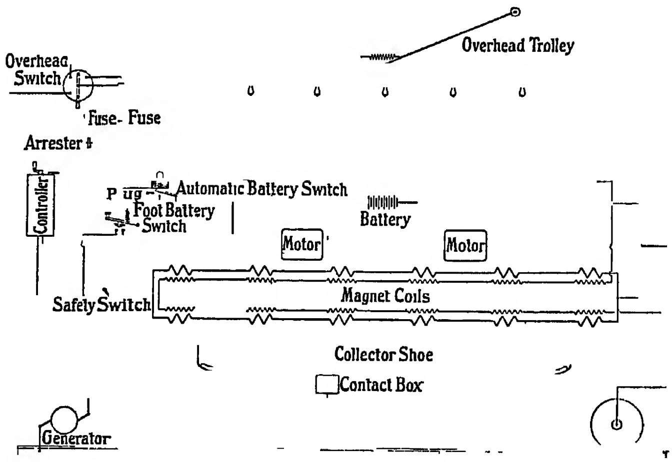


Fig. 1089.—Diagram of Car Wiring as arranged for combined Contact and Trolley Lines

the magnetic pull, which increases the life of both studs and skate. Both shunt and series coils are used, either of which are strong enough to work the switches, so that both sets of coils must be disabled before the skate becomes inoperative. The coils are former wound, taped, and enclosed in brass cases filled up with bitumen, and in practice have given no trouble.

The moving part of the switch is much lighter than in the Diatto or Dolter systems, and consequently works more rapidly and with less damage to its contacts, and will work satisfactorily up to 30 miles per hour.

The sources of loss of power in this system are similar to those in the Diatto and Dolter systems. In practice it has been found that 15 to 20 per cent more power is required than with the trolley system working under similar circumstances.

It will be noted that the magnetic lines of force from the skate pass in such direction relative to the switch, that they would blow out any arc formed between the carbon contacts.

In the system shown in fig. 1090 the action of the magnetic skate on the button magnetizes it, thus attracting the small casing, which is free to swing on its pivot. By raising this casing the mercury contained in one

end of it flows down and makes contact with the terminal, which is flexibly connected to the continuous conductor, thus establishing electrical connection between it and the contact-stud. The skate acts as a collector as well as magnetizing the contact-stud

(4) **Heavy Iron Skate.**—The systems of this group might equally well be classified as electromagnetic systems. They present some excellent features, and are deserving of more attention than they have received up to the present time, as they dispense with the objectionable and expensive magnetic skate

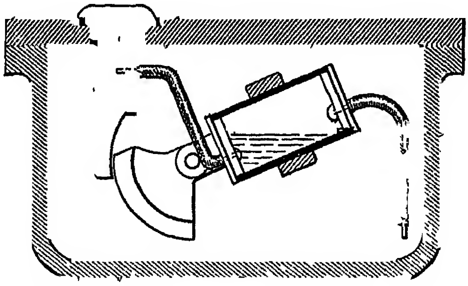


Fig 1090 —Magnet on Car tilts Case and Mercury closes the Circuit

This system is shown in fig. 1091 The magnetic skate is replaced by a simple heavy iron skate, which can also be used as a collector. This iron skate closes the magnetic circuit, and thus enables the magnets contained in the switch-box to lift the armature and make the required connections. The magnet coils in the switch-box may be continuously energized from a separate circuit, or the action of the armature may be such as to switch the current through the coils in the advance switch-box The electromagnet with which the skate was about to come in contact would first be energized; upon the iron skate closing the magnetic circuit the armature would be attracted When so attracted it would close its own circuit and retain its magnetism independently of the rear switch-box, and energize the coils in the advance box It will be seen that at least one box would have to have its electric circuit closed before the next one could be operated, and thus an ordinary magnetic connection, such as would be caused by a heavy wagon wheel on the two exposed ends, would not cause the magnet to attract this armature.

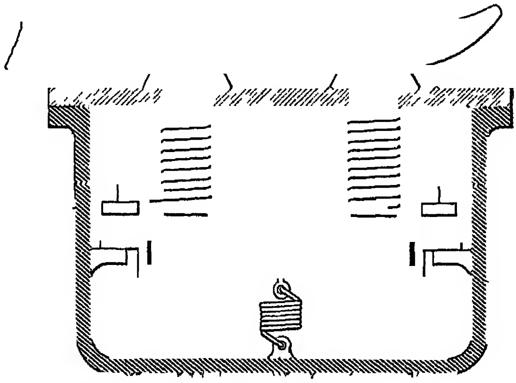


Fig 1091 —Heavy Iron Skate closes Magnetic Circuit, enabling Magnets to close Switch

Another modification of this principle has been worked out with some care and detail, and is known as the Thompson-Walker system. It is one of the most instructive, and possesses a good deal of originality.

The system consists of a single row of contact-studs which are energized by an automatic switch worked by a solenoid, which is actuated in the first instance by a current from a battery carried on the car, and there-

after by a current from the collector-skate The most striking novelty in this system is the method of moving the automatic switch, which is quite different from anything which has been heretofore proposed. A solenoid of wire carrying a suitable current is provided In this is an iron plunger, fitted loosely and perfectly free to move in a vertical direction. By so proportioning the heads of this plunger the magnetic attraction of the solenoid for the head counterbalances the tendency of the plunger to assume a central position in the solenoid, so that the action of gravity will cause the plunger to assume the position shown in No 2, fig 1092 When a piece of iron is placed immediately over the plunger its magnetism acting upon the piece of iron causes the plunger to assume the position shown in No 3, fig 1092. If it is desired to use a heavy plunger, a great part of its weight may be supported by the magnetic attraction of the solenoid by slightly increasing the size of the lower head. The action of the plunger is somewhat sluggish, and in order to accelerate the movement the plunger is so constructed that there is a small air-gap between the head and the body, as shown in No 1, fig 1092. If a mass of iron is placed over the plunger before the current is sent through the solenoid, the instant the current passes through the solenoid the attraction upon the head is so great that the plunger moves very rapidly before it comes in contact with the head. Thus a hammer blow on the head is effected, which overcomes its inertia and actuates the switch with great rapidity.

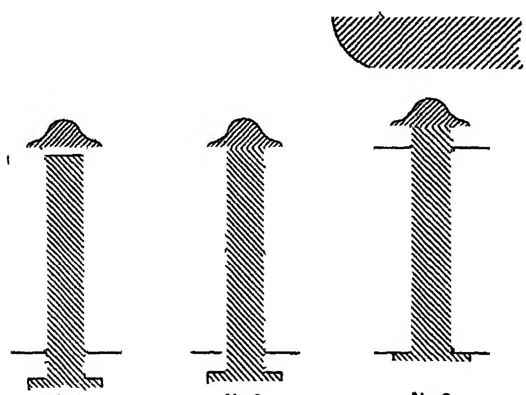


Fig 1092 —Thompson-Walker System—Positions of Plunger

A section of the switch mechanism is shown in fig 1093 The switch is in the closed position It consists of a circular cast-iron box with a lid of gun-metal S, which lid forms the contact-stud The lid is fixed into a gun-metal ring, which is insulated from the cast-iron box by a sheet of micanite. The space about the stud is filled up with asphalt to the level of the road The plunger P is surrounded by a very loose brass tube enlarged at its lower end T, so as to give room for the lower head of the plunger P, which is perfectly free to slide in the tube, and can have as much clearance as may be necessary. The tube T can itself slide in an outer tube, upon which is wound the solenoid To the lower end of the tube T, but insulated from it, is attached a yoke Y This yoke when the switch is closed completes the electrical connection between the two brushes C_1 and C_2. The whole switch is immersed in oil, and sufficient suction exists between the plunger P and the tube T, notwithstanding the large clearance, to enable the plunger in falling to carry down the tube T with it, thus opening the switch. If from any reason the tube T and yoke Y should stick, the

plunger P will slide down through the tube T, and by means of pin N make connection between the yoke piece and the earth, as shown in fig. 1094 This will connect the feeder directly to earth, which will blow fuse f in fig. 1094.

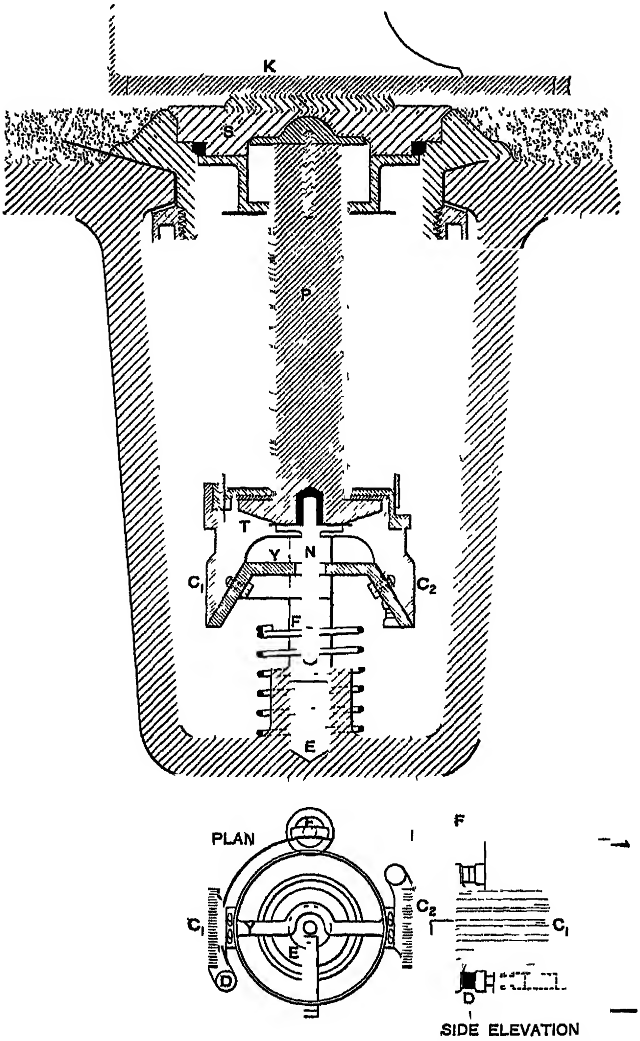


Fig 1093 —Thompson-Walker System—Section and Details of Contact-Box

The action of the system is as follows:—The diagrams 1095 and 1096 show the electrical connections of the system. In fig. 1095 switch No. 1 is closed, and current is flowing from the main feeder F through the fuse f, contacts C_1 and C_2, to contact-stud S, skate K, and through the motors to earth. In the diagram the yoke between C_1 and C_2 is drawn as a separate piece from the plunger, but they must be considered as rising and falling together, as above described. In fig. 1096 it will be noticed that the

moment skate K touches the stud of No. 2 switch, the current passes from it round the shunt-coil, magnetizing the plunger, which rises and is held up by its attraction upon the iron skate K. By slightly tapering the ends of the skate the mass of iron is brought over the plunger a little before the electrical contact is made, thus securing the rapidity of action on the part

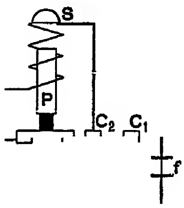


Fig 1094 — Thompson-Walker System — Connection of Earthing Device

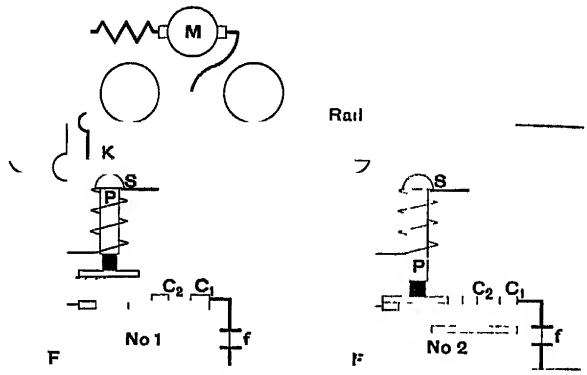


Fig 1095 — Thompson Walker System — Diagram of Connections

of the switch already described As soon as the skate K leaves the contact-stud of switch No. 1 it falls by gravity and leaves the contact-stud dead.

The skate used in this system is a simple bar of iron, with no complications in the way of magnetic coils, &c, which is a point of distinct superiority over most systems, but the contact-stud, being made of gun-metal, is soft, and will wear badly.

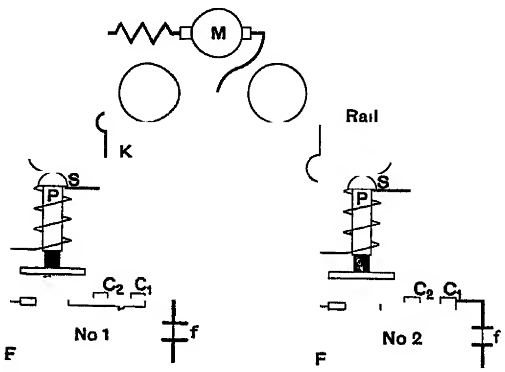


Fig 1096 — Thompson-Walker System — Diagram of Connections

It will be noted that in order to move the switch it is necessary to pass a current through the solenoid and bring a mass of iron above the switch The possibility of these events happening simultaneously, except when intended, is exceedingly remote. There is not a great possibility of the tube T and the yoke Y fig. 1093 sticking in a closed position, and that possibility can be minimized by slight alterations in the design of the contacts Should this happen, there is practically no chance of the plunger P also becoming jammed. And if the plunger is free it will blow the fuse, even if the tube had become jammed

It will be noted that the safety of the public from the question of live contact-studs has been very carefully considered. It would, of course, be possible to use with this system a supplementary short-circuiting skate, which would blow the fuse should the safety devices have failed to work.

One disadvantage of this system is that the No. 2 stud, fig. 1096, is only energized by the contact of the skate, and should this be covered with dirt or ice, and fail to establish electrical connection before leaving No 1 stud, the No 2 switch would fail to act, thus bringing the car to a stand-still It would also be difficult to find an oil that would not thicken with cold weather to some extent, which would tend to render the action of the switch somewhat sluggish The switch is so designed that by taking out two or three screws in the stud the entire switch can be lifted clear. The whole operation should not take over a minute or two

This system has not been used in actual service, but an experimental line on private ground at Willesden appears to have worked very well

CHAPTER IV

ELECTROMAGNETIC SYSTEMS

The electromagnetic systems afford a very wide field for ingenuity on the part of the inventor, and a very large number have been patented They may be divided into two groups —

1 Those in which each switch is a unit and works independently of all others

2. Those in which the switches are interconnected to a greater or less extent

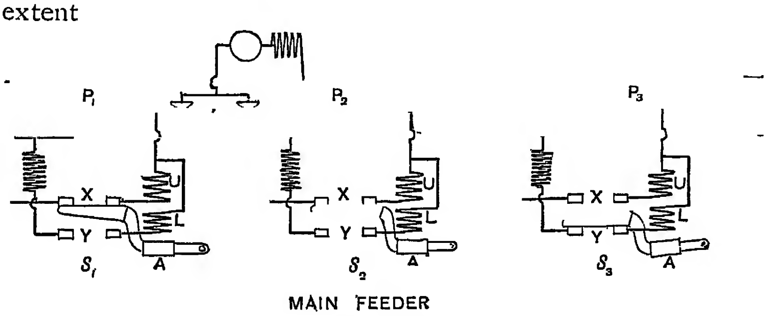


Fig 1097 —Diagram of Dr Hopkinson's System

(1) **Independent Switches.**— The earliest electromagnetic system falls in the first group, and was patented by Dr Hopkinson in 1882 This is shown in fig. 1097. A single row of sectional rails or contact-studs is provided, and brushes in multiple, or a collector-skate of sufficient length to come in contact with two studs at once, is used, a storage battery being used to close the first two switches The normal position of the switch is shown in S_3 The current from the battery passes in multiple from contact-studs P_1 and P_2 through the coils L in S_1 and S_2, and through the contacts Y, attracting the armature A, causing the switch to come in contact with terminals X. The current then flows from the main feeder, through the contacts X, coils U, to the contacts P_1 and P_2, from whence

it is collected by the brushes or skate and taken to the car As the car proceeds the battery is cut out, and the pick-up of the advance switch is made by the main current. It will be noted that the coil U is in series with the motors, and so cannot fall until the car has passed, but is then free to fall by gravity. This prevents arcing, but any leakage

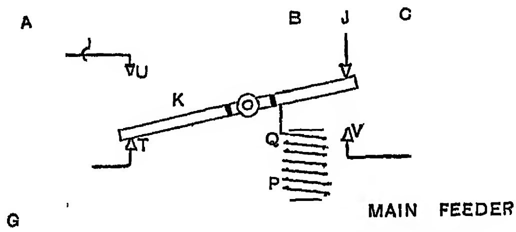


Fig 1098 —Diagram of Ayrton and Perry System

from the sectional conductor to rail would tend to keep the switch closed and the sectional conductor alive

In 1883, Ayrton and Perry proposed the arrangements shown in fig 1098 The rail A B being alive when the contact reaches J, the current passes through contact T, electromagnet coil P Q, to J. This actuates the lever K, and closes the circuit between contacts U and V This

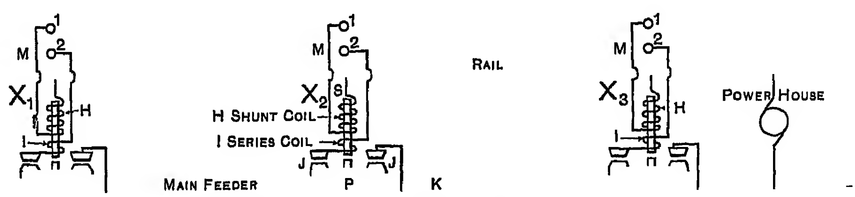


Diagram of Switch Connections (Westinghouse)

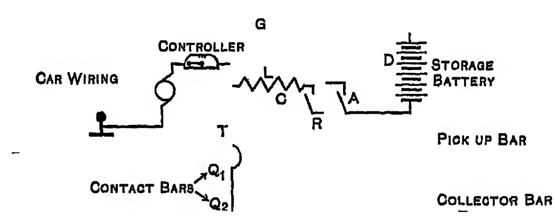


Diagram of Car Connections (Westinghouse)

Fig 1099

completes the circuit between continuous conductor G and the sectional conductor.

The Westinghouse system requires a shunt and a series coil to be used at each switch. The former establishes contact between the feeder and the contact-stud, and the latter increases the pressure of this contact There are two series of studs, one used to actuate the shunt coil of the switch, and the other for drawing off the main current.

Fig 1099 shows the general arrangement of the system clearly in diagram. Each car is provided with two spring contact-skates Q_1 and Q_2. These skates are mounted the same distance apart as the contact-studs 1 and 2 The contact-skates are long enough to come in contact with two studs at the same time If a car is standing with the contact-skates in contact with their respective

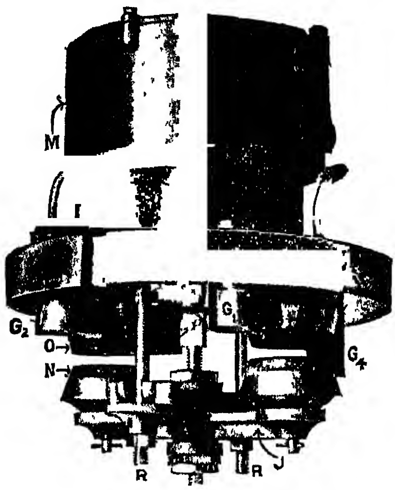


Fig 1100 —Westinghouse System—Details of Contact Box, showing Switch

studs, for example at X_2, the switch A is first closed, which allows the current from the small storage battery D to pass through the conductor R, to the skate Q_1, stud No 1, and shunt coil H, to the rail The current passing through the shunt-coil H draws up the armature P, closing the

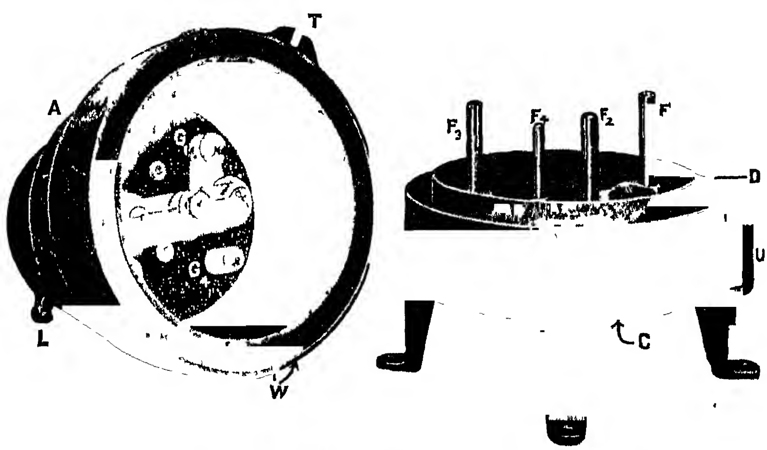


Fig 1101 —Westinghouse System—Details of Contact-Box, Switches removed

switch and establishing a connection between the 500-volt main feeder K and stud No. 2, through the carbon contacts J J and series-coil I. The switch C is now closed and switch A opened, cutting out the battery. The switch X_2 is kept closed by the current flowing through series-coil I, stud No. 2, skate Q_2, conductor T, controller, and motors to rail. The current

to close the advance switches now flows from T through resistance L, switch C, conductor R, skate Q_1, stud No 1, conductor M, and coil H to the rail. As the car advances and the contact-skates make connection with the next pair of studs at X_3, the operation becomes automatic and the battery is not brought into action at all As soon as the skates leave the studs, the current ceases to flow, and the armature P falls back by gravity. As

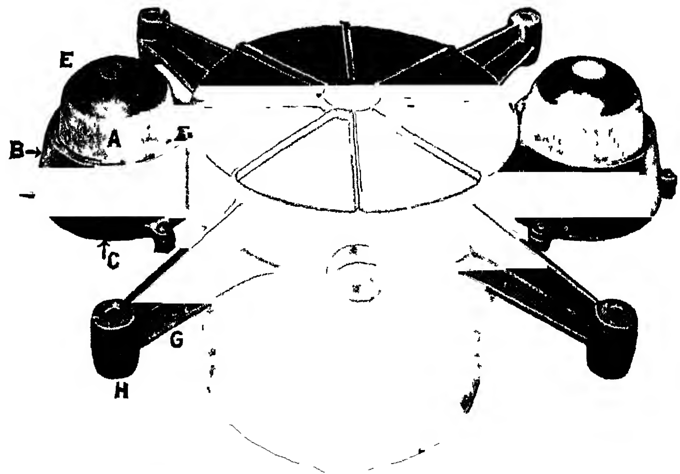


Fig 1102 —Westinghouse System—Switch-Box and Contact-Stud for Railways

the coil holding the switch closed is in service with the car, it cannot open while there is any current flowing, so no arc occurs in the switch

Details of the electromagnetic switch are shown in figs 1100 and 1101 The switch magnet M is protected by an iron casing, and is provided with a fine wire or shunt coil for the pick-up current, and a coarse wire coil, which is in series with the main current This magnet attracts an armature attached to a bridge-piece J, each end of which carries

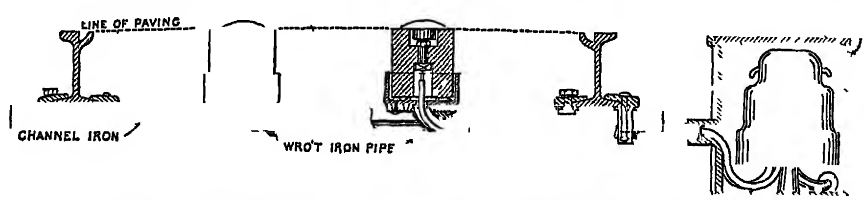


Fig. 1103 —Westinghouse System—Section of Track equipped for Tramway Service

a carbon disc N. R R are guides for the bridge-piece. The carbon discs N make contact with the carbon discs O, which are attached to the marble base of the switch. One of these is permanently connected with the positive main feeder, and the other through the series-coil to the contact-stud 2 (fig. 1099) It will be noted that the switch provides a double break for the current A pan C (fig. 1101) is provided with four pins F. These pins slide into receptacles G in the switch base. These pins are insulated from the pan C, but are provided with ter-

minals for connection to the main feeder, rail, and contact-studs The whole pan is filled with paraffin-wax after the connections have been made. The upper part of the switch is then slipped over the pan and

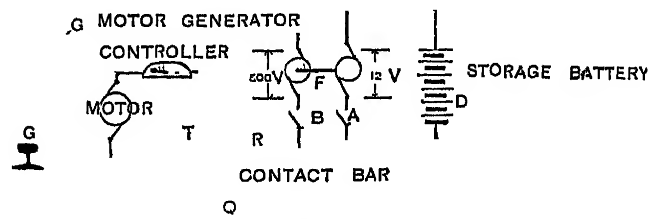


Fig 1104 —Westinghouse System—Diagram of Car Wiring

sealed, on the diving-bell principle This arrangement is made to provide for the easy removal of the switch for replacement or inspection

When the switch is designed for use on a railway, it is combined with two contact-studs E as shown in fig 1102, and supported by the four arms H to the cross ties. If intended for use on a tramway, the

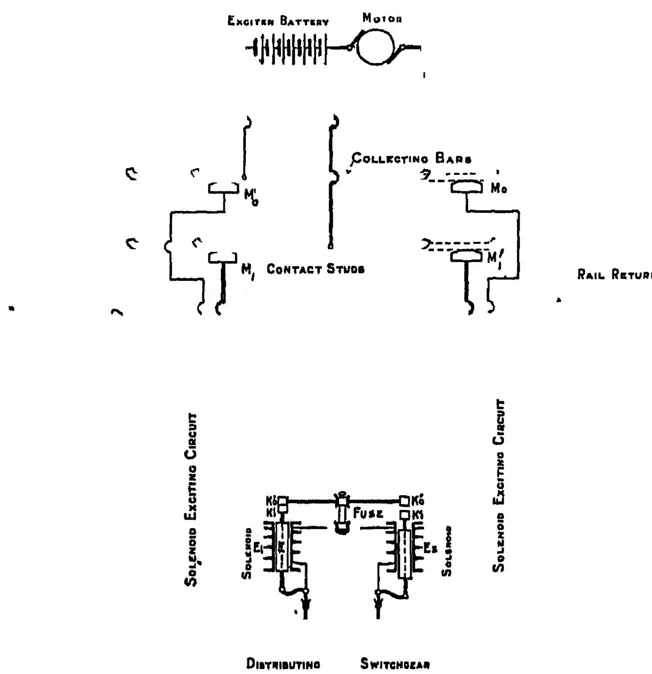


Fig. 1105 —Helios System—Diagram of Connections

arrangement used is shown in fig. 1103. The switch mechanism is placed in a cast-iron box at the side of the track, and cast-iron contact-studs, embedded in suitable insulating material, are placed between the rails. The switches could, if so desired, be grouped together in convenient distributing chambers located at some distance from the track. If it

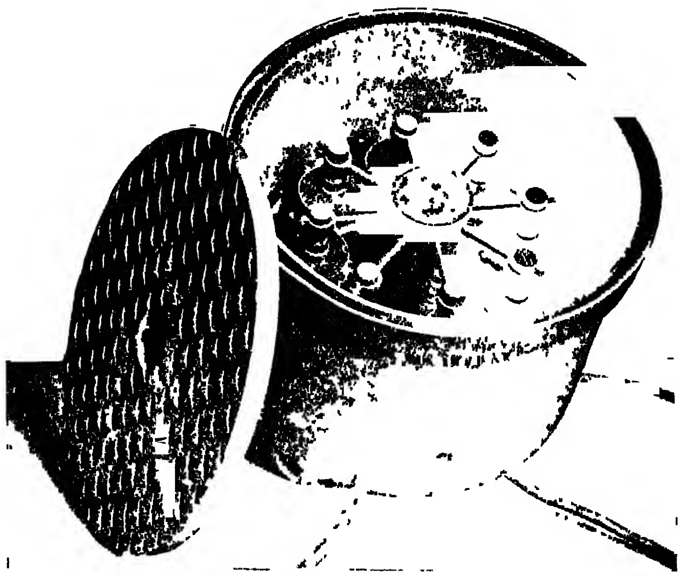


Fig 1106 —Helios System—Switches in Water tight Box

is desired to use only a single row of studs, the pick-up current must be at the same voltage as that of the main circuit Under these cir-

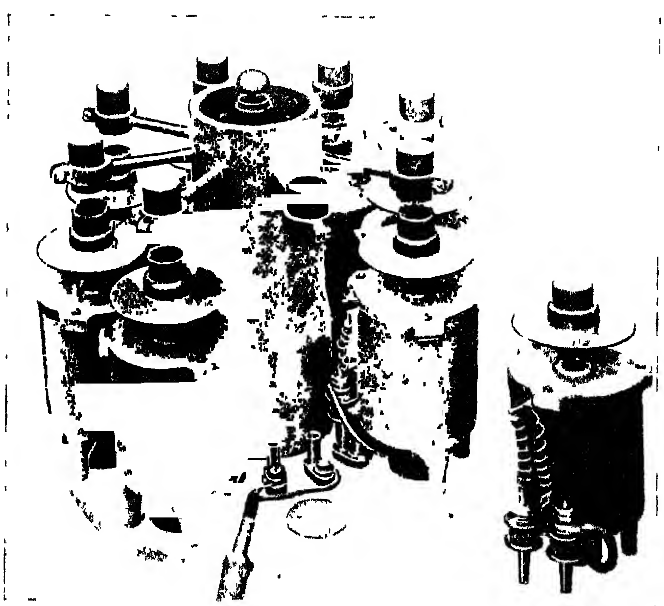


Fig. 1107 —Helios System—Group of Switches, showing Method of removing a Single Switch

cumstances the car wiring shown in fig. 1104 is used Switch A is first closed, which completes the circuit from a storage battery D through

a small 500-volt motor generator F. In a few seconds, when this has got up to speed, switch B is closed The pick-up current then passes through conductor R to contact-skate Q, and then through the magnet switches as previously described. As soon as connection has been established to the contact-stud, the motor generator may be stopped. This high voltage pick-up is of advantage where the track is liable to be obstructed with snow and mud

This system has been in successful operation for a number of years on a heavy goods railway at Indian Head, Maryland, U.S.A., but has not as yet been used on a tramway.

Referring again to fig. 1099, it will be noted that a very small leakage current between the contact-studs would be sufficient to energize the shunt-coil II, thus retaining the armature P in position and leaving the contact-stud No. 2 alive This would be a very serious drawback to the system in tramway work, and would have to be overcome before it could be considered practicable in this country

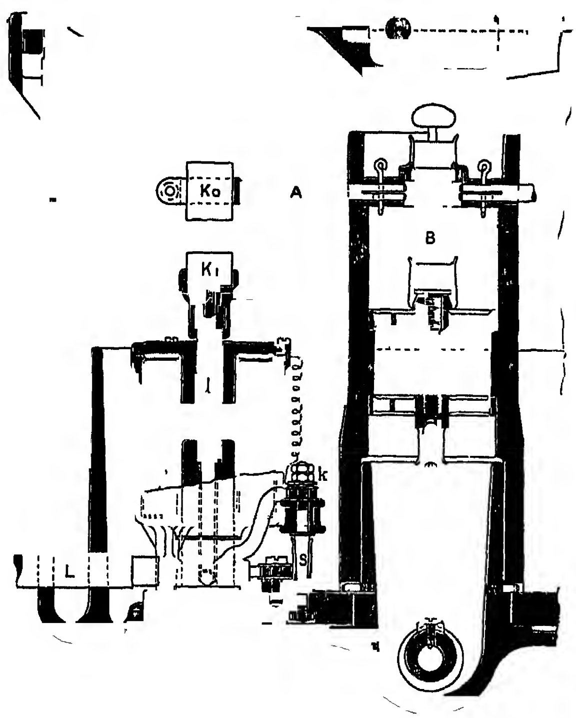


Fig 1108 —Helios System—Section of Switch and Water tight Contact-Box

The system worked by the Helios Electrical Construction Company is electrically nearly identical with the Westinghouse system, but the details have been cleverly worked out, and although it has the same faults, it is worthy of some attention.

The chief electrical differences are the absence of the series-coil in the magnetic switch (the movement being entirely accomplished by a shunt-coil), and the fact that the switches, instead of being close to each contact-stud, are arranged in groups of eight, and placed in a cast-iron box circular in shape, in a convenient position. Fig. 1105 shows clearly the electrical arrangement of the system.

Figs. 1106 and 1107 show the group of switches, and fig. 1108 shows the section of the switch. It will be seen that there are eight radial arms, each provided with a carbon contact at the outer end. The inner end is permanently connected to the main feeder The shunt-coils are so arranged that when the current from the storage battery is passed

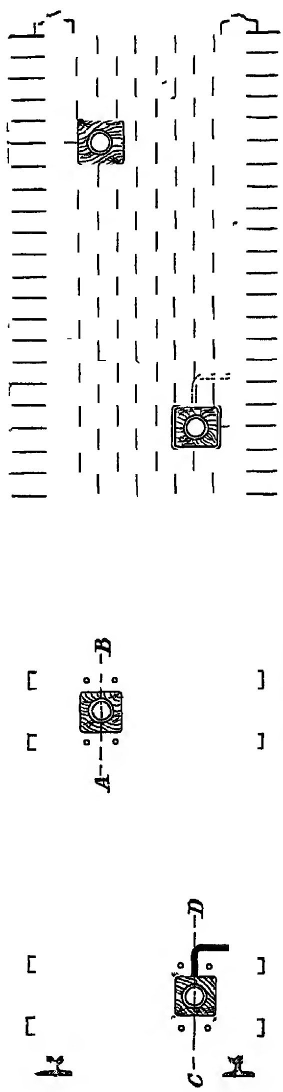


Fig. 1109 —Thomson-Houston System—Plan of Track

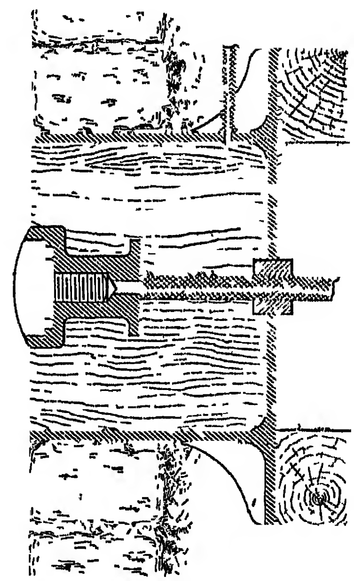


Fig 1111 —Section of Contact-Stud at C D

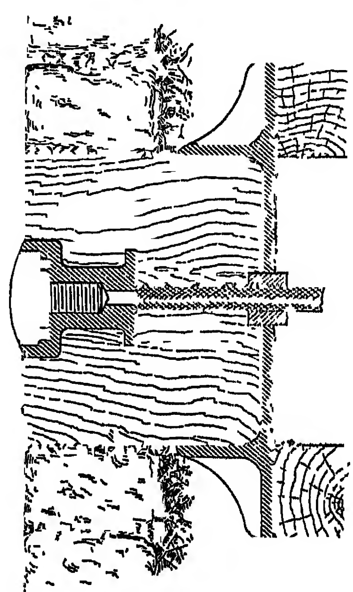


Fig 1110 —Section of Contact-Stud at A B

through them, they force out the magnet cores, making contact between contacts K_1 carried by them and those carried by radial arms K_{11}, the lower end of these cores being connected by flexible wire which runs to the terminal *k*, the circuit is thus complete between the feeder *l* and the contact-stud Each one of the eight solenoid switches is quite independent and can be removed for inspection or replacement with the greatest ease. Fig. 1107 shows one of them removed It will be seen

that there are a pair of socket terminals provided on the base of the switch, into which the plug terminals on the solenoid are forced, so that the solenoids may be removed by simply being lifted out.

(2) **Interconnected Switches.**—The French Thomson-Houston Company installed a surface-contact system of this type in 1898 at Monaco on a tramway about 3 miles in length, which has been worked with a fair degree of satisfaction

As will be seen in referring to fig. 1109, two rows of contact-studs are required These are placed about 1 foot from the rail and are of two types—one a high-tension contact shown in section A B, fig 1110, and the other a low-tension stud shown in section C D, fig 1111 In both cases the contact-stud is embedded in a block of wood In the high-tension stud the block rests on an iron chair, which is secured to two adjacent sleepers In the low-tension stud the iron chair is carried

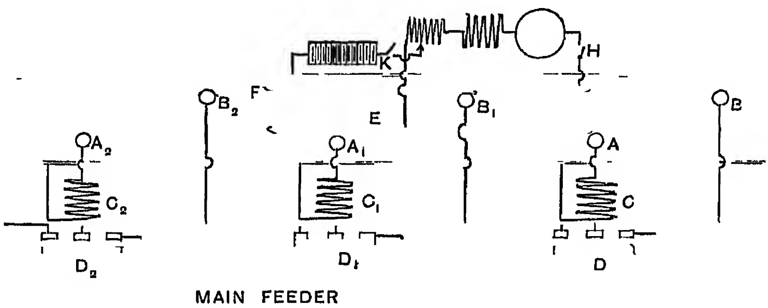


Fig 1112 —Thomson-Houston System—Diagram of Connections

up to form a box, the edge of which is flush with the surface of the paving This box is connected by a suitable cable to the rail Both studs are so designed that the wearing portion can be easily removed and replaced when worn down by the action of the contact-skate The contact-skate is about 13 feet in length, which is sufficient to make contact with two studs simultaneously.

The action of the system can be followed from fig 1112. B, B_1, and B_2 are the high-tension contact-studs, A, A_1, and A_2 the low-tension studs C, C_1, and C_2 are magnet-coils which actuate a switch with three contacts. One of these contacts is permanently connected to the main feeder, the other two are connected to two adjacent high-tension contact-studs. The first movement of the controller closes the switches H and K The closing of switch K brings into action a small storage battery. The current passes through a portion of the starting resistance of the motor, the skate E, contact-stud A_1, coil C_1, to the rail, and thence back to the battery. The battery current energizes the coil C_1, which attracts the armature D_1, which consists of an iron bar with three carbon contacts electrically connected to it. These carbon contacts are pressed against the three copper contacts of the electromagnetic switch. This enables the current from the main feeder to pass through the armature D and the three contacts above referred to, to the high-tension studs B_1 and

B_2, from which it is collected by the skate F, and conveyed thence to the motors. From the motors it passes through skate E to the low-tension stud A_1, thence through coil C_1 to the rail While the controller is on the first notch and the switch K closed, the current from the motors divides, part of it passing through the storage battery to earth, and part through the coil C_1. This arrangement keeps the storage battery automatically charged.

The next movement of the controller opens switch K and allows all the current to pass through the coil C_1. The skate will reach low-tension contact A before it has left A_1. The current from the motors then divides, part of it flowing through C_1 and part through C This closes both switches D and D_1, so that high-tension contacts B, B_1, and B_2 are all alive at the same time, and it will be noted that the high-tension contact B is energized before the skate F comes in contact with it, which adds greatly to the certainty of an electric contact being made As soon as the skate E leaves the stud A_1 the current ceases to flow through coil C_1, and the armature D_1 falls by gravity The switch is so designed that, should any current be flowing through the switch when the armature D_1 falls, a magnetic blow-out extinguishes the arc without damage to the contacts It would be impossible for a leakage current to hold the switch C_1 closed, as, in order to do so, it would have to pass from the high-tension contact B_1 to the low-tension contact A or A_1, and the low-tension contacts are provided with a metallic shield, already described, which would short-circuit any leakage current to the rail, the iron case above referred to being securely connected to the rail. The distance between the studs B_1 and A_1 is considerable The only possibility of the high-tension studs being left alive is that of armatures D_1, D_2, and D_3 failing to fall, owing to some mechanical obstruction. It would, of course, be possible to provide the car with a short-circuiting skate to guard against this somewhat remote chance, but it does not appear to have been done

The switches are arranged in groups located in water-tight chambers beneath the surface of the road. It will be noted that the high-tension contact-studs are very close to the rail, the distance being about 1 foot This is so close that a leakage current might in bad weather be quite a serious item Also, that the distance between the low-tension studs and the iron box, which is connected to the rail, is very small, and that a connection established between these two would short-circuit the magnet coils and prevent the switches from acting The difference of potential between these two points is, however, small, being only the fall of potential in the magnet coil itself, so this could not be a serious danger. The chief drawback to this system is the necessity for two sets of contact-studs.

The Johnson-Lundell system was tried in New York in 1894 or 1895 on an experimental line in 34th Street, arranged as shown in fig 1113, and worked with a fair degree of success

The chief feature of this system is the use of two sets of sectional conductors, one located between the rails, and the other close to, but just outside of the rails, for which a third rail arranged in sections was used.

It will be noted that each switch is provided with two coils U and L, and that the sections of the sectional rail are permanently connected to the running rail, through coil U on switch 1 and coil L on switch 2. The contact-studs P_1, P_2, P_3 are not connected with the coils in any way, but by means of the switches 1-2-3 are successively connected direct to the main feeder. This avoids any possibility of the armature A being held up by a leakage current from studs P_1, P_2, P_3 to the rail. Two collector-skates C_1 and C_2 are required. C_1 is of considerable length, but C_2 may be short and in the form of a brush, as it is only necessary for it to bridge the small gaps in the sectional rail. Supposing the contact-skate C_1 to be resting on stud P_2, the action of the system is as follows —

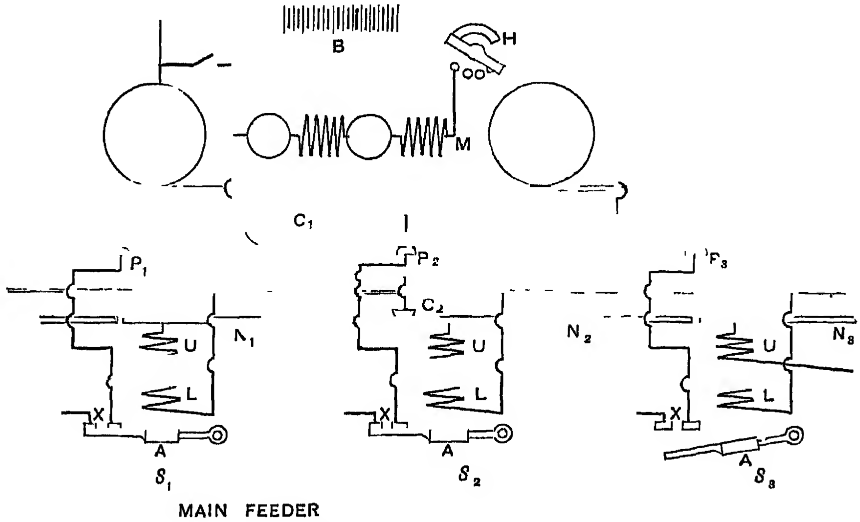


Fig 1113 —Johnson Lundell System—Diagram of Connections

The switch H is closed, allowing the current to flow from the battery B through the switch H to M, thence through the motors to the skate C_2, thence through the sectional rail N_1, coil U (S_1), coil L (S_2) to the rail, and thence by the wheels of the car to B. The action of the coils U and L closes both switches S_1 and S_2, and allows the current to flow from the feeder main through the contact X (S_2) to the stud P_2, and from there through the skate C_1 to the switches H and M, through the motors to skate C_2, thence through N_1, coil U (S_1), coil L (S_2) to rail. The car in moving to the right brings the skate C_2 in contact with the next section of the sectional rail N_2, and breaks contact with section N_1. The current will then flow from C_2 through the coil U (S_2), coil L (S_3) to the earth. This will hold up switch 2, close switch 3, and allow switch 1 to open by gravity. And this action is always repeated by the progress of the car. The advance switch is always energized before the skate reaches it, which adds to the certainty of a contact being made. Any tendency of surface leakage from studs P_1, P_2, P_3 to sectional rail N_1, N_2, N_3 would tend to energize the magnet

coils and keep the contact-studs alive, but such leakage current is impossible, for in order to reach the sectional rail it would have to cross the running rail, which is the return circuit A 500-volt storage battery was used, which was connected in multiple with the motors across the main circuit, and it was proposed to make this battery of sufficient capacity to run the car for some distance. Only certain portions of the track, including the ascending gradients, were equipped with surface-contact devices; on these portions the battery was being automatically charged, so as to run the car over the portions of the line where the contacts were not fixed, the idea being to minimize the number of contacts required

A good deal of work was done on this system, and the details were worked out with considerable care, but beyond the experimental line above

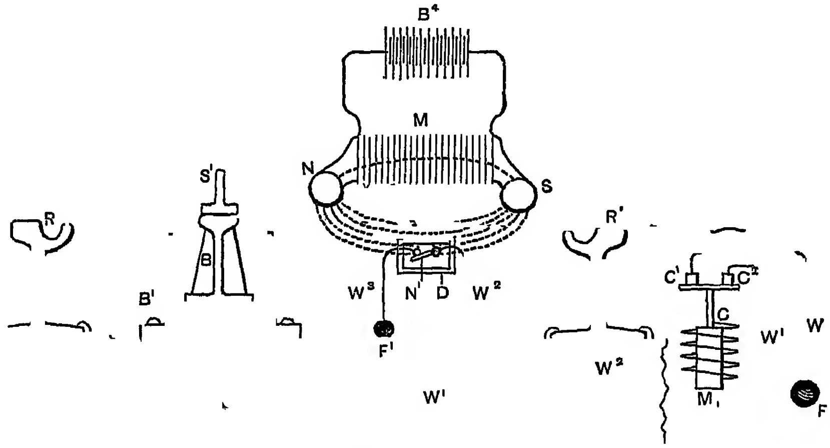


Fig 1114 —Johnson-Lundell New System—Section and Diagram

referred to, it has never been used in actual service More recently Messrs. Johnson-Lundell have developed a system differing considerably from the above, and shown in diagram in fig 1114, but this system has also never been put into actual service It is a combination of the magnetic and electromagnetic systems, and the 500-volt battery has been dispensed with A series of contact-studs B are provided in the usual way, which studs are placed somewhat out of centre of the track These studs are connected to the main feeder F by conductor W^1, contacts C^1 and C^2, and the armature of coil C The car is provided with a collecting-skate S^1, which rubs on contacts B, and also with an elongated magnet M energized by the main current or by a battery B^4 This magnet is provided with two long pole-pieces N and S, which are connected and energized by several magnet coils in a manner very similar to that described for some of the magnetic systems D is a small air-tight and water-tight switch-box of non-magnetic material, located beneath the surface of the road bed. In this water-tight box is an iron needle N^1 which, when raised by the action of the magnetism of the pole-pieces N and S, makes contact between the conductors W^2 and W^3. This completes the circuit between low-tension feeder F^1 and the coil

M_1. The feeder F^1 conveys a low-tension current (which is supplied from the generating station by an independent generator), and which is of just sufficient potential to energize the coil M_1, and after passing through this coil returns by the rail to the generator. The low-tension circuit having been closed by the action of the pole-pieces N and S by the needle N^1, the low-tension current energizes coil M_1, which forces the armature C into contact with the terminals C^1 and C^2. This completes the circuit from high-tension feeder F to contact-stud B. By making the magnet M somewhat longer than the skate S^1, the needle N^1 will keep the stud B alive until after the skate S^1 has left it. So no arcing will take place at the contacts C^1 and C^2 except that due to breaking the leakage current, which is negligible.

It will be noted that the arrangements proposed do not differ in principle from the Diatto system, but they appear to have added some rather unnecessary complications. If the box D is placed close to the surface of the street, considerable difficulty will be experienced in maintaining the paving on top of it. If placed at a sufficient depth to accommodate the paving, it will very largely increase the gap in the magnetic circuit, which would counterbalance the small amount of saving in magnetic attraction derived from the light weight of the needle N. Also, should needle N fail to fall, for mechanical reasons, no means appear to have been provided for cutting the current off from the stud B. The addition of the low-tension feeder F^1, with the necessity for another type of generator in the station, does not seem to have any compensating advantages.

The Claret-Vuilleumier system is one of much ingenuity and interest, and has been in actual service in both Lyons and Paris, in the latter city three and a half miles were constructed about the year 1895, and are still working.

A single row of contact-studs are provided between the rails. These studs are spaced about 8 feet apart or more, according to the length of the car. No switch mechanism is provided immediately beneath the contact-studs, but two studs are connected in multiple, and each pair is connected to a point of a commutating switch which controls a convenient number of studs. Each car is equipped with a collector-skate of sufficient length to make connection with the advance contact-stud before it has left the last one.

The general arrangement of this system is shown in fig. 1115. The commutating switch consists of a convenient number of contact points, Nos. 1 to 12, arranged in a circle, and three arms insulated from each other and capable of being rotated so as to bear upon the contacts successively. Each of these arms is provided with and electrically-connected to an independent collector-ring. Upon these collector-rings bear brushes or sliding contacts, by means of which the current is transmitted from the main feeder F to the several contact-studs in the track. The centre collector-ring is connected directly to the feeder F. The narrow contact-arms are somewhat longer than the broad contact-arm. One of the contacts, 12, is so designed that when the switch is rotated only the narrow arms touch this contact, the broad arm at this point being at zero and the circuit open between the main feeder F and the contact-studs on the track. The arm in connection

with the centre ring carries a contact of sufficient width to bear up two adjacent contact-points at the same time. The other two arms are narrow and break the circuit each time they leave a contact-point Both these arms are connected by separate circuits to the magnet-coil C, which actuates the commutating switch by means of a double pawl and ratchet, one circuit and pawl being used when the car is running forward, and the other when the direction is reversed.

When the car is in such a position that the skate bears on either of the contact-studs of pair 5, the current flows from feeder F through the wide centre arm of the switch to contact-point 5, and thence to the contact-studs of pair No 5 in the street, to the skate, and through the motors to the earth As the car moves to the right, the skate will engage one of the contact-

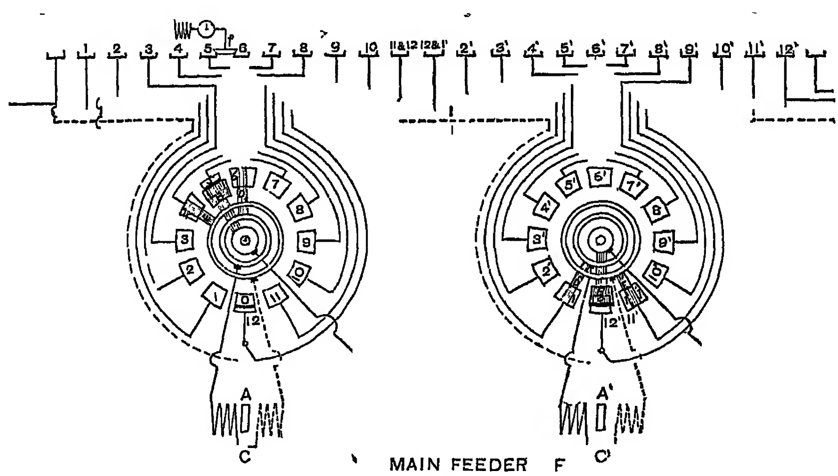


Fig 1115—Claret-Vuilleumier System—Diagram of Connections

studs of pair 6 and the current will divide, part passing through the motors, and part from the skate through contact-studs of pair 6, switch contact-point 6, through the right-hand arm D, to magnet C, and thence to earth The magnet C being energized, attracts the armature A, which by means of a pawl and ratchet moves the commutating switch one step forward—that is, the distance between one contact-point and the next. In making this step the wide contact-arm touches 6 before it leaves 5, consequently the circuit is not broken and a continuous flow of current is maintained to the contact-studs in the track. This action continues until the skate touches the pairs of contact-studs marked 11–12′ and 12–1′. The current then flows from feeder F through the centre arm on contact-point 11, thence to stud 11–12′, to the motor circuit, and to earth, also through the skate pair 12–1′, thence to the outer point of the double contact 0–12 of the left-hand commutating switch, and also to contact-point 1 of the right-hand commutating switch This operates both commutating switches at once, bringing the centre arm of the left-hand switch to zero, and that of the right-hand switch to contact-point No. 1′. This action energizes studs 12–1′ from the right-

hand commutating switch, and disconnects stud 11–12′ from feeder F. The action is then repeated through the series of contact-studs

It will be seen from the above that each commutating switch controls a section of track to which it delivers current step by step, the commutating switch assuming the zero position when the car leaves that section and all the contact-studs are dead. The connections are, however, such that the contact-switch begins to move and delivers current to the contact-studs as soon as the collector-skate of the next car touches the first contact-stud of the group. Each commutating-switch is placed in a convenient position under either the surface of the roadway or footpath, and is enclosed in a water-tight chamber with a manhole cover

This system exhibits a great deal of ingenuity in design and has proved fairly satisfactory, but is complicated, expensive to install, and the maintenance is said to be high As it is only possible to energize at one time two adjacent pairs of studs out of any group, it is impossible to operate more than one car at a time on that particular section This forms a sort of automatic block system, which is very undesirable in tramway practice, particularly so on busy portions of a line, where it is frequently necessary that cars should follow each other at very close intervals Should a car accidentally run by its momentum into a section already occupied by the preceding car, it would not be possible to start until the preceding car had left that section, and until the commutating-switch had been turned by hand, so as to energize the particular contact-stud under the car If from any reason the collector-skate failed to establish a good electrical contact with any one of the contact-studs, either from wear or from the stud being coated with ice or other insulating medium, the advance contact would not be energized, and the missed contact would be left alive in the street Should the momentum of the car have carried it beyond this contact, it would be necessary either to move the commutating-switch by hand until the stud under the car became energized, or to push the car back by hand until the skate came in contact with a live stud These troubles have happened frequently in practice The cars cannot be run backwards except for the length of the skate, without specially setting the commutating for a change in direction

Messrs. Pringle and Kent, working independently in England, developed, patented, and published accounts of a system of surface contact which is practically identical with the Claret-Vuilleumier system, except that they use a sectional rail instead of contact-studs, but it does not appear that it was ever put into service

In the Esmond system a sectional conductor is used situated between the tracks, and divided into 4-feet lengths, with short gaps between. The sections are arranged in groups of four (fig. 1116), Nos 1 and 3 being permanently interconnected in multiple, and in series with the switch-coil L, and No. 2 is connected in series with the coils L and U, and No. 4 is a dummy section used to maintain the mechanical continuity of the collector-rail. The car is provided with four brushes, A B C D (fig 1116), each long enough to bridge the gap between the sections. A and C, B and D are connected in multiple with each other, the former group

being connected to one terminal of the storage battery carried on the car, the latter to the other terminal of the storage battery and to the motors. The switch H is provided to close the battery circuit. The contact between the feeder F and the sectional conductor is established in the first instance by the use of the battery B. By closing the switch H, a current will flow to brush A, sectional rail 1, through the upper half of the magnetic coil U_1,

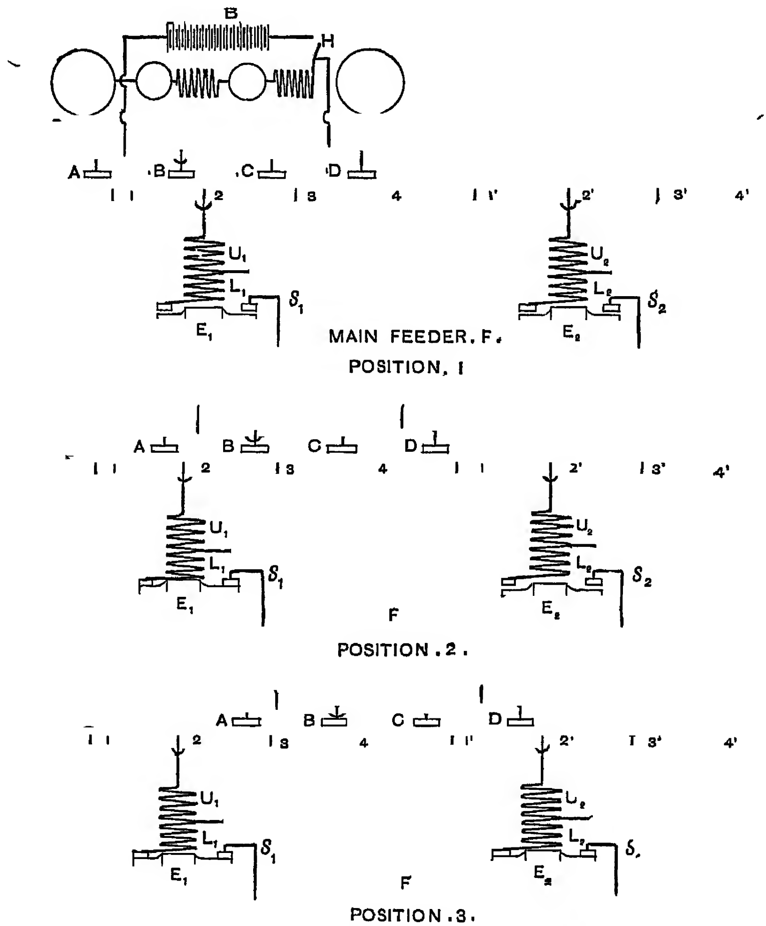


Fig 1116—Esmond System—Diagram of Connections

sectional rail 2, brush B to the battery. The coil U_1 if energized attracts the armature E_1, closing the circuit between feeder F and the sectional conductor. The current then passes through both the upper and lower coils of the magnet, sectional rail 2, brush B, to the motors, and thence to the rail.

When the car moves to the second position the current flows through the lower portion of the switch-coil, sectional rail 3, brush B, to the motors and rail. When the car moves to the third position, the current is still flowing through the lower half of the switch-coil L_1 and sectional conductor 3, from thence by brush A to brush C, sectional conductor 1′, the upper portion

of the switch-coils U_2, sectional rail 2′, group 2, brush D, to the motors and rail The fourth position is in effect the same as the second position, except that the current is drawn from sectional rails 1′ and 3′ in multiple, and thereafter the cycle repeats itself

This system was tried upon an experimental line of about half a mile in length at Loughborough, about the year 1897. The switches were not placed beneath the track, but a considerable number were grouped together at one point. The line worked fairly well, but the system was never put into actual service

It will be noted that this system is especially liable to have the sectional conductor kept alive by surface leakage after the passing of a car, for three

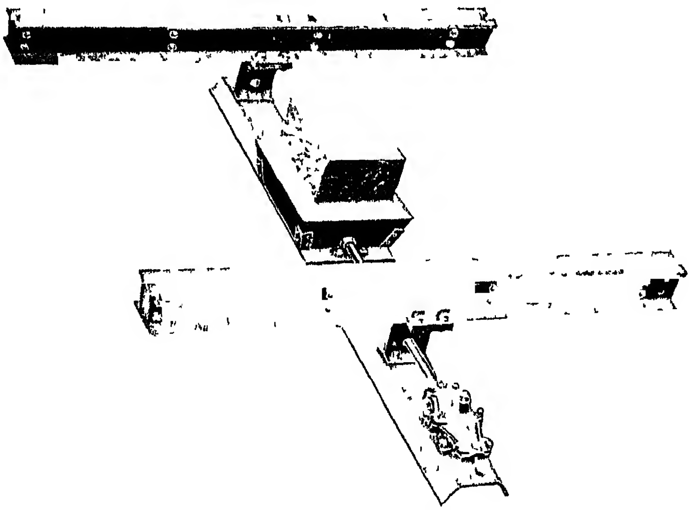


Fig 1117 —Schuckert System—Contact Stud

consecutive sections, aggregating some 12 feet in length, give a large surface for leakage current, which must all pass through a single switch-coil

The Schuckert system has been in use in Munich since 1899 As first installed it was very complicated and had serious drawbacks, chief among these was the inability to run the car backwards for more than two or three yards without manipulating a reversing switch located somewhere along the line of route.

Recently the system has been much simplified and the most serious defects eliminated, and it is now one of the most practical of the surface-contact systems

It consists of a single row of studs which are mere contact points, no mechanism being located in their immediate vicinity. These contact-studs are bolted to steel sleepers to secure alignment to the track, but are carefully insulated from the sleepers The arrangement is clearly shown in fig. 1117. The switches controlling the contact-studs are grouped together in a chamber below the level of the street (figs. 1118, 1119), these chambers being located about 100 yards apart. It would, of course, be possible,

perhaps preferable, to group these in a pillar-box, similar to a feeder pillar as used in the trolley system. The switches are so arranged that those

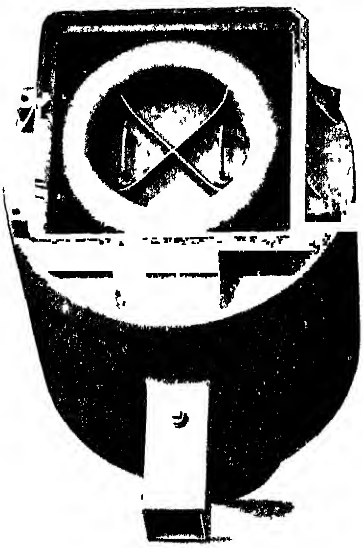


Fig 1118 —Schuckert System—Switch Chamber, showing Water tight Cover

Fig 1119 —Schuckert System—Switch Chamber, showing Interior

controlling alternate contact-studs are interconnected, but there is no connection between the switches controlling adjacent contact-studs

At first sight the system appears somewhat complicated, but in reality the electrical connections of each pair of switches

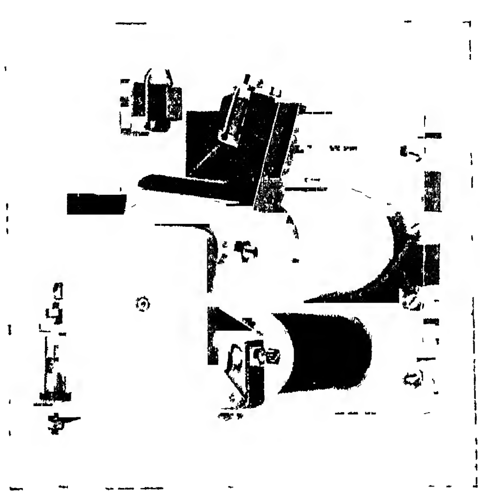


Fig 1120 —Schuckert System—Contact-Switch

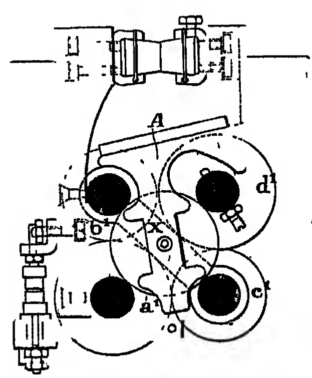


Fig 1121 —Section of Schuckert Switch Apparatus

are quite simple. One of the switches is shown in figs. 1120 and 1121. Each switch, as will be seen, is provided with two pairs of magnet-coils.

One pair, $b'c'$ (fig. 1121), act as draw-on coils to close the switch, and $a'd'$ as draw-off coils to open the switch. The draw-off coils are divided into two sections, only one section being in use at a time. Each switch is provided with two contacts fitted with carbon blocks, the main contact seen at the top of the switch and a short-circuiting contact shown at the left hand of the switch In addition to the magnetic force of the draw-off coils $a'd'$ the switches will open by gravity The movement of the main switch lever about the pivot X is very slight, and it fits very loosely on the pivot The wires interconnecting the several pairs of switches are secured to the walls of the distributing boxes The switches are provided with spring contacts, which slip into the clips, so that they may be easily removed for inspection or replacement The coils of the switches are so wound that the maximum difference of potential in the coil is about 25 volts This renders a break-down of the insulation extremely unlikely The coils are in shunt across the main circuit, and require ½ ampere of current A resistance is provided in series with each coil to prevent this being exceeded. As two coils are in use at once it will be seen that the amount of current wasted in the switch mechanism is 1 ampere per car, which would increase the consumption of current about 5 per cent over a trolley line

Fig. 1122 is a diagram showing the working of the system. It will be noted that the collector

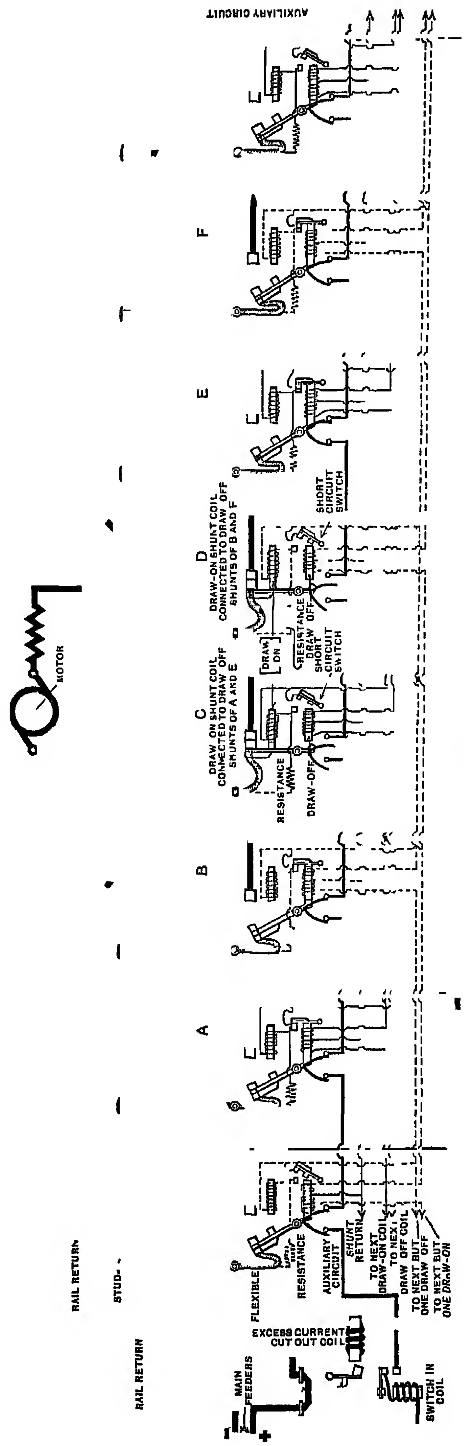


Fig 1122 —Schuckert System—Diagram of Connections

skate rests upon the contact-studs connected to switches C and D. The current passes from the main feeder through both switches C and D to the motors, and thence by the rail return to the generator. A proportion of the current, $\frac{1}{2}$ ampere, passes through the resistance and draw-on coils of switch D and then divides, a portion passing through the draw-off coil of switch F and thence to the shunt return, the balance passing through the draw-off coil of switch B and thence to the shunt return The current passing through switch C acts in a similar manner, but passes through the draw-off coils of switches A and E respectively. It will be noted that the path of the current in the various switches is symmetrical, and is the same in the advance as in the rear switch Consequently the car will run with equal facility in either direction. It will also be noted that the small short-circuiting switches of A, B, E, and F are closed. This is incidental to the working of the system, but not essential. The use of these switches will be seen below

As the car advances so that the skate comes in contact with stud B, the current passes from the skate through the resistance and short-circuit switch of B, thence to the draw-off coil of switch D. When the draw-off coil of switch D is energized, it closes the short-circuit switch, which short-circuits the draw-on coil of D and allows the draw-off coil to open the switch D. The skate having left stud D, and the draw-off coil having opened the switch, no current can flow through the resistance and short-circuit switch, and the draw-off coil of switch B is demagnetized, allowing the short-circuit switch to open by gravity. Upon this short-circuit switch having opened, the current from the skate flows through the draw-on coil of switch B, closing the main switch and allowing current to flow from the feeder to the contact-stud and skate The opening of switch D also cuts off the current from the draw-off coil of switch F, and allows the short-circuit switch to fall by gravity to its normal open position This series of switch movements continue to take place as the car proceeds

It will be seen that, owing to the action of the short-circuit switch, it would be impossible for a leakage current from stud to rail to hold a switch closed. Each car is provided with a short-circuiting skate which, in event of any stud remaining alive after the collector skate had passed, would cause a short circuit and open the circuit-breaker in the distribution-box. The circuit-breaker, it will be seen, is provided with a switch-in coil connected to an auxiliary circuit, which passes through all the switches, and is so connected that if, after the circuit-breaker has acted, all the switches had opened as they should do by gravity, and consequently all the studs dead, the current would be automatically switched on to the main feeder again If the failure of a switch to open had been permanent the auxiliary circuit would not be closed, and the line would remain dead until the fault had been cleared. This is a very ingenious and useful device, as it enables the protection of the safety skate against live studs in the street to be utilized without the risk of disabling a section of the line on account of the sluggish action of one of the studs This arrangement effectually overcomes the difficulty of short circuits between skate and rail at crossings caused by scrap-metal in the streets

The arrangements for re-establishing the connection between the feeder and the stud, either in starting or after the contact has been accidentally lost, present some novel features. If the car is moving at the time, and the controller is turned to the first braking position, the motors acting as generators will work the switches and re-establish the contact If the car is stationary, a small generator is provided on the car, which can be turned by hand by the driver, and is so geared that a couple of turns of the handle will operate the switch and re-establish the contact. This is a vast improvement over the usual method of pick-up by means of a storage battery

The collecting device is also novel. In place of the rigid skate so frequently used, a link chain is employed, extending nearly the full length of the car The chain is suspended at several points by spiral springs, and springs are also employed at each end to keep the tension on the chain This link-chain collector is absolutely noiseless in operation, and being flexible is less easily damaged by obstructions in the street, and can be worked with less clearance Owing to its flexibility it should materially reduce the wear on the studs

This system has been very carefully worked out in detail, and avoids many of the faults of other systems It has, however, two drawbacks — First, the advance stud is not energized before the skate comes in contact with it, and the action of the advance switch depends upon a contact being established between the skate and stud If this contact should fail to be made, the draw-off coil in the rear switch would not act, and the rear switch would be left alive, and it would then depend entirely upon the short-circuiting skate to render this stud safe Second, the multiplicity of wires running into each distributing box It is necessary where these enter the box to bunch them together, and a fault in one of them is very liable to damage a considerable number, and would be rather an expensive matter to repair Unless these wires are of considerable section they appreciably increase the drop in the feeders, and if of large section they seriously increase the cost

The Schuckert system, although somewhat more expensive to install than the modifications of the Diatto principle, should be slightly more economical in the use of current and less expensive in upkeep, owing to the better arrangements for dealing with short circuits and the greater simplicity of the contact-studs and collecting devices

CHAPTER V

SUMMARY

It will be seen that many of the systems described are inherently unsuitable for tramway purposes, and consequently their application is extremely limited. The success of any system of surface contact will depend almost entirely on the amount of skill shown in the working out

of details, and judgment in the selection of suitable materials, especially insulating materials In fact, the failure of many of the earlier systems may be attributed to the impossibility of obtaining suitable insulating mediums. The majority of inventors have also usually been deficient in either mechanical or electrical training, or in an intimate personal knowledge of the conditions under which the system must work, and the practical tramway engineer, who had the necessary qualifications, has not found it to his advantage to devote the necessary time and energy to perfecting a surface-contact system

The mechanical systems cannot be considered seriously, owing to the great expense and obvious disadvantages of the conduit, which they practically all require

The progress made in magnetic systems is much more encouraging Several examples of the Diatto system and its modifications, notably the Dolter and Lorain systems, are working with a very fair degree of satisfaction The latter exhibits unquestionably the best judgment in the choice of material and arrangement of detail The great drawback of all of these systems is the difficulty of constructing the switches to withstand the inevitable short circuit caused by the magnetic skate The magnetic skate is heavy and cumbersome, and adds at least 10 per cent to the weight of the car, and requires a relatively large amount of power to energize, picking up any stray bits of iron that have been dropped in the street, which are sure to make a short circuit at the first junction

Of the electromagnetic systems, the Thomson-Houston at Monaco and the Claret-Vuilleumier system at Paris has proved fairly satisfactory, but the most promising of this group is the Schuckert system The multiplicity of wires and other complications required by the majority of electromagnetic systems makes both first cost and maintenance high, and detracts from the reliability of the systems Another drawback common to most magnetic and electromagnetic systems is the necessity for the use of a storage battery of greater or less dimension, to re-establish connection to the feeder should it be accidentally lost through momentary failure of the current The greatest difficulty that remains to be overcome in all surface-contact systems, and one which has not yet been seriously dealt with owing to the experimental character of most of the surface-contact lines, is that of points and crossings The working out of details of any surface-contact system at a complicated junction—as, for instance, the crossing of two lines of double track with three or four interconnecting curves of small radius, necessitating the superelevation of some of the rails, and the whole perhaps complicated by irregular cross-sections of intersecting streets—would form a problem that would require much skill and ingenuity to solve

Conclusion.—The conclusion that we must come to, in considering surface-contact systems, is that there are several that an engineer could recommend with confidence for use under special circumstances, where the extra capital cost and operating expenses would be justified, but there are none that appear to be entirely satisfactory for application to an extended and complicated system of tramways

6. Conduit Systems of Electric Traction

CHAPTER I

INTRODUCTION

Conduit systems of electric traction are those in which the moving cars are supplied with current from conductors fixed in a conduit or tube below the track, by means of a current collector or plough carried by the car, and passing through and along a continuous slot in the surface of the roadway.

They may be divided in two ways—

Open and closed conduits
Shallow and deep conduits

The great difficulty with which conduit systems have to contend is that due to the entrance of mud, water, dirt, &c, into and through the slot from the surface of the roadway

Open and Closed Conduits.—The idea of the closed conduit was to get over this difficulty by the use of some mechanical arrangement by means of which the slot opening was under ordinary circumstances closed, thereby preventing foreign matter from entering the conduit, the arrangement being such that the plough could force aside the closing mechanism, which shut again after the car had passed Several arrangements were worked out on this principle, but they all appear to have failed owing to dirt forcing its way in and preventing the proper operation of the closing or opening mechanism One form of the Bentley-Knight system was constructed with the slot rails supported at the outer lower edges and free to fall together, thereby closing the slot Dirt, however, worked in behind these slot rails and prevented their free movement. The arrangement is shown in fig 1123.

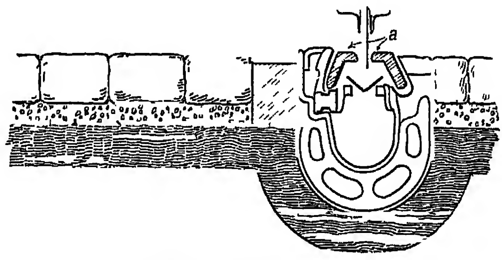


Fig 1123 —Bentley-Knight System *a*, Slot-closing rails

All the conduits which have survived are *open* conduits.

Deep and Shallow Conduits.—The closed conduit was in reality an attempt to render feasible the operation of the shallow conduit, which, as its name implies, was a channel of small depth, the object being to avoid the more or less considerable excavation required by the deeper forms of conduit. The liability of the conduit becoming choked with debris, thereby preventing the operation of the particular system, has also prevented their being successful

Many shallow conduits have been devised, some of which are interesting. One such system consisted of a plough of a length somewhat less than that of the car, and constructed so as to be to a certain extent flexible. This collector was supported at two or more points from the car truck, and was so arranged that, as it was carried along the conduit with the passage of the car, it forced its way between projecting contacts placed at regular intervals These contact pieces made contact with the positive and negative collecting surfaces on each side of the plough, and being at the same time pressed outwards by its passage, made contact at the other end with an insulated cable by means of a type of bayonet-switch. When the car had passed, these contact pieces were forced outwards by spring action, and thereby became disconnected from the circuit. The switch-gear was contained in water-tight boxes, and the whole depth of the conduit was not more than that of the tramway rails

A similar type of shallow conduit is also employed with the Kingsland surface-contact system for operating the stud switches. In this case, however, pits are provided at intervals of about every 15 to 20 feet, into which, it is claimed, all debris entering through the slot will be carried by the action of the strikers on the car.

As far as the writer is aware no shallow or closed conduit system is being continuously operated under the conditions of everyday service, and there remain therefore only the deep and open type of conduit

Open and Deep Conduits.—The introduction of conduit systems was due to the objection made in some places to the adoption of the overhead trolley system, principally on æsthetic grounds One of the first ideas was to make an arrangement in which the overhead trolley wire, instead of being placed above the track, should be placed underground in a conduit, and reached through an opening in the surface of the roadway

The earlier structures were distinguished by being, as a rule, shallow, and with wide slots frequently so constructed that the conduit could be opened up for the purposes of cleaning by removing the detachable covers forming the road surface These points are illustrated respectively very strongly in the Love conduit system, which was put down in Washington, and the arrangement of removable conduit covers adopted in Dresden and Blackpool

The Love Conduit System.—The Love conduit system, after being exhibited at Chicago, was installed on a length of about 1¼ mile of track in Washington, and was probably the oldest line in America working on a conduit system, and was in more or less successful operation up to 1900, after which the construction was modified in accordance with modern practice.

Fig. 1124 shows a section of the Love conduit. Two conductors were employed, consisting of copper wires carried on insulators supported from the yokes, contact was made with these by means of a bar carried below the car passing through a slot in the surface of the roadway, and carrying

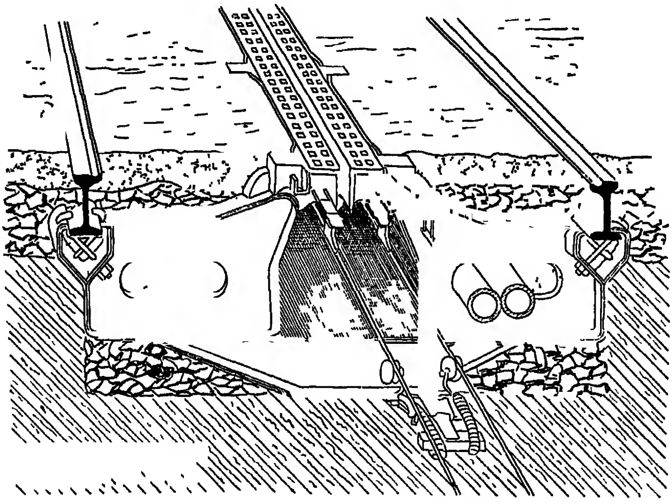


Fig 1124 —Love Conduit

at its lower end a double trolley with trolley wheels pressing against the under side of the above-mentioned conductors

The arrangement of the conduit itself was a deep conduit, the depth of excavation being about 2 feet, with yokes 4 feet apart, and was on the whole in accordance with modern practice. The system was, however, ultimately replaced owing to difficulties introduced by the expansion of the conductors causing them to deviate from the straight, thereby producing frequent short circuits and tendency for the trolleys to jump the conductors

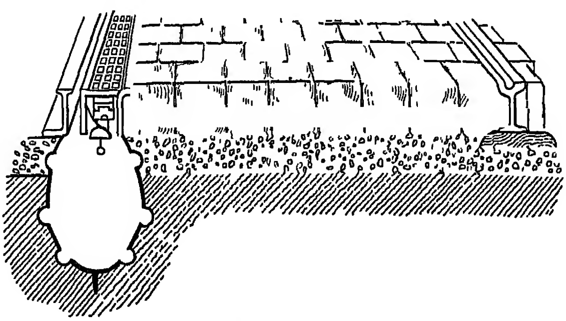


Fig 1125.—Dresden Conduit

Dresden. — The conduit in Dresden was fixed under one of the running rails, and was made accessible over its entire length by means of cast-iron plates forming one side of the slot Owing to these plates having a certain amount of lateral play the slot was wide and somewhat irregular, varying between 1 and 2 inches. Fig. 1125 shows a section of the track and the removable covers to the conduit.

Blackpool.—Fig 1126 shows a section of the Blackpool conduit. This

was also accessible over its whole length, but having in most places two conductors, has a cover on each side of the slot.

Although undoubtedly the Holroyd-Smith conduit had various defects—and it must not be forgotten that the line in Blackpool was laid down in 1884—its ultimate removal from Blackpool was due not so much to these as to the fact that any conduit system would have proved unworkable in its position, the line being at times flooded with sea-water heavily laden with sand, completely choking the conduit No system of drainage could prove effective in such a case.

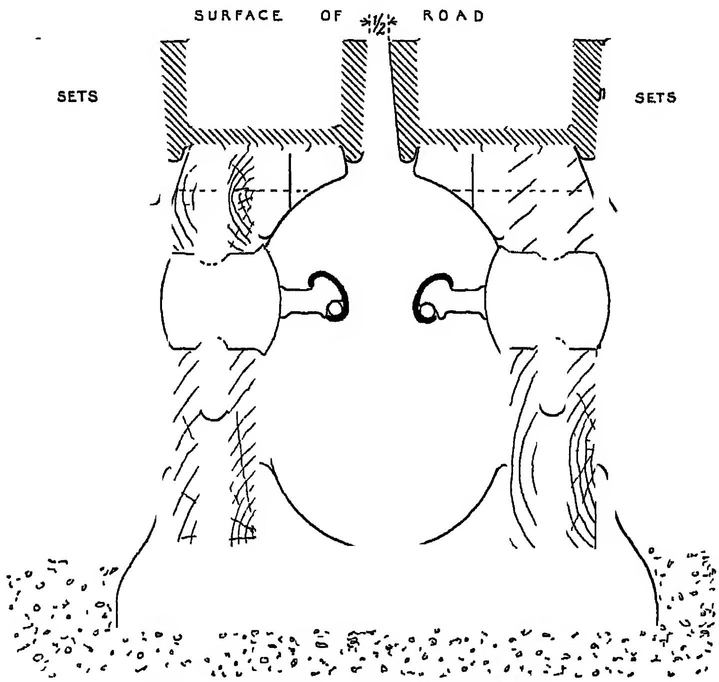


Fig 1126—Transverse Section of Conduit, Blackpool Electric Railway

Conduit lines have been constructed in various places on the Continent and in America, including Buda-Pesth, Dresden, Paris, Berlin, Brussels, Lyons, Washington, New York, Chicago, and Baltimore. Before, however, going into details of these systems, it may be well to consider the general lines on which the modern conduit has been developed and the conditions which it is required to fulfil

Owing to the determined and continued opposition of certain American cities—notably New York and Washington—to the use in their streets of the overhead system, the American street car companies were obliged to seek some other method of operating their systems and avoiding these objections The American companies already knew what could be done with a frequent service of rapid cars owing to their experience with the cable system. The heavy cost of maintenance, however, made them

anxious to try some other alternative. They were not afraid, therefore, of incurring considerable capital outlay

The first section of electric conduit in New York was built entirely as an experiment, and the design of the conduit was so chosen that should the electrical arrangement prove unsatisfactory, the line could be converted to cable traction at comparatively small cost It may be added, however, that the engineers in charge of the design and construction of this work did not anticipate any necessity for the adoption of this course. The experiment proved entirely successful, the lines since constructed have been laid down on a similar design, and there are now at work some 20 miles of conduit system in New York alone. It may thus be seen that the modern conduit is a direct outcome of the experience gained with the cable system It has been developed chiefly by the General Electric Company in America, and by the affiliations of this company and Messrs Siemens & Halske on the Continent

CHAPTER II

ADVANTAGES AND DISADVANTAGES OF THE CONDUIT SYSTEM

The great claims made on behalf of the open-slot conduit system as designed to-day are —

(1) That the electrical conductors being entirely underground and out of reach, absolute safety is secured to the public

(2) That the working of the regular service on this system is as free from interruption as with any other system of mechanical operation

(3) That there are no overhead wires, poles, or other obstructions in the roadway

The great drawbacks to the system are its great initial capital cost, the increased cost of operation due to the expense incurred in maintaining and cleaning the conduit, and existence of the slot in the roadway usually with its attendant extra pair of slot rails In this latter connection, however, it is pointed out that with a slot not exceeding $\frac{5}{8}$ to $\frac{3}{4}$ inch, and with narrow slot rails, or still more so where the conduit is constructed under one of the running rails, this latter objection is of small weight Slots of $1\frac{1}{4}$ inch and over, and constructions which are apt to be specially wide at points, such as may be found in some places on the Continent, would never, however, be tolerated in this country.

In designing a conduit system a number of points have to be taken into consideration, most of which vary according to local conditions

Climate.—The question of climate is not of paramount importance, as in this respect the conduit system is at no greater disadvantage than other systems of traction, with perhaps the exception of very heavy rainfall. Suitable provision must be provided for draining the conduit, sufficiently ample to deal with the heaviest rainfall likely to occur, due consideration being given to the gradients, so as to avoid the likelihood of water accumulating at certain points of the route. Cases have occurred,

however, in which, in spite of exceptional rainfall, the car service has been maintained through short, flooded sections of conduit without greater difficulty than that of providing the extra leakage current consumed This has occurred on two or three occasions in Washington, while, on the other hand, serious interruptions have been occasioned by the same cause in Vienna. The difference in the two cases has probably been brought about by the extent of the track flooded in one case being much greater than in the other, the leakage of current under these conditions being very considerable

State of the Roadway and Cleaning.—The state in which the roadway is maintained is usually a matter under the control of the local authorities, and has an important bearing on the cost of maintenance of the conduit system It is perfectly clear that provision has to be made for the periodical removal of all extraneous matter finding its way through the slot into the conduit. The amount of such matter depends to a certain extent on local conditions and on the way in which the roadway is kept, and if the road cleaning is carelessly or inefficiently performed the work involved may be considerably increased

According to local conditions it will be found necessary to place the cleaning pits closer together in some places than in others, and this depends to a certain extent on climate

The method of cleaning adopted by different companies operating with conduit system appears to vary considerably The system yielding the best results appears to be that in which the conduit is cleared at regular and frequent intervals In New York the conduit is cleared *daily* by means of a scraper attached to a horse wagon The result is that the actual amount of matter to be removed is very small, and there is no possibility of any accumulation forming in the conduit

In Brussels, where there are about 14½ miles of double track on the conduit system, the cleaning of the slot and conduit is done by a gang of about ten men, who go systematically over the whole system about once every seven days. There is little doubt, however, that the daily system of cleaning adopted in New York is the more satisfactory method, and accounts for the excellent state in which the New York conduit is maintained The cost of cleaning in New York is given as 055 of a penny per car mile

Type of Paving.—The type of paving with which a conduit track is paved is important, because on account of other traffic it is desirable, there being possibly three sets of rails instead of two, that a good even surface is maintained, and so laid that it tends to throw rain-water, &c, away from the slot, and secondly, on account of the necessity, particularly in this country, where the width of the slot is limited, of maintaining the slot at the right gauge.

On account of the high capital cost of tramways constructed on the conduit system it is unlikely to be used, except in the central areas of large towns or where for other reasons the overhead construction is inadmissible. In such positions the paving already in existence will generally be either asphalt, wood (either creosoted or Australian timber), or some form

of granite sett, and will extend not just over the width of the track but over the whole width of the roadway.

Granite and asphalt paving present no special difficulty, but in the case of wood-paving precaution has to be taken to construct the conduit of ample strength to resist the expansion of the wood when thoroughly soaked with water, as otherwise the closing up of the slot will result.

With wood-paving as usually laid, a space of from ½ to 1½ inch according to the width of the roadway is left clear on each side between the paving and the curb in order to allow for this expansion This allowance, however, is frequently insufficient, as is shown by the forcing of the curb-stones out of position, which sometimes takes place. It is by no means easy to arrive at a correct estimate of the pressure which wood-paving is capable of exerting in this manner It is, however, undoubtedly considerable, and from some rough experiments has been estimated at about 2½ tons per lineal metre Where wood-paving is in use, the general practice is now to lay the space between the tracks with well-faced granite setts

CHAPTER III

GENERAL CONSIDERATIONS

Construction.—In considering the design of conduit and its equipment, alternate methods of construction suggest themselves They may be discussed under the headings of—

Central *v* Side Slot,
Rigid *v* Flexible Conductors, and also
Single *v* Double Insulated Conductors

It will probably simplify matters to discuss the electrical considerations involved first In this respect there are two possible arrangements, namely —

(1) That in which both positive and negative conductors are insulated and placed in the conduit, and

(2) That in which the track rails are employed for the return circuit.

Most of the earlier conduits belong to this latter class, including the systems laid down in Blackpool, Dresden, Buda-Pesth, as also in the Waller-Manville or Simplex system That these systems have not received further extension has been due not so much to an inferiority in the single-conductor design as to defects in other more important details.

The difference is an important one Where the return circuit is by the track rails, the conduit contains conductors of one polarity only, and the whole attention of the designer can be devoted to making the insulation of the unipolar conductor or conductors as perfect as possible The difficult problem of designing the conductor arrangements at crossings and turn-outs is hereby also very much simplified

From an electrical point of view the problem resolves itself into two questions: of insulation and continuity of supply. Mechanically it affects most of the details of construction, which will be dealt with as they arise The question of continuity arises only at points and crossings. Where both poles are insulated, and conductors of each polarity are fixed in the conduit, it is obvious that at crossings and points the conductor bars have to be interrupted The interruption is, of course, smallest at crossings, but may amount at points and special work to lengths of 12 feet and over. In order to meet this difficulty, it is necessary either to equip the car with two collecting-ploughs placed sufficiently far apart to enable them to bridge any gap in the conduit conductors which may occur, or the car has to travel through such gaps by its own momentum, and should by any chance a car be stopped in such a position, external force has to be applied to set it in motion. This, however, with good management is seldom likely to occur, and the principal drawback is the extinction of the car lighting which occurs at such spots at night-time Where, on the other hand, conductors of only one polarity are used in the conduit, such interruptions of the conductors at crossings are not absolutely necessary, and at points, by the employment of two conductors, one on each side of the plough, the supply is continuous whichever branch the car takes

Rigid v Flexible Conductors.—It may be well here to consider for a moment the question of rigid and flexible conductors. Flexible conductors are continuous, rigid conductors jointed. As mentioned above, one of the first ideas in the construction of a conduit system was to build an underground trolley system The Love system was designed on this principle, and was a double-conductor system. The difficulty with flexible conductors arises from the fact that increase of temperature produces an expansion of the conductor. The conductor not being rigid, such expansion will produce a sagging unless mechanism is provided for taking up such expansion as occurs In the Love system a spring mechanism was provided, but owing to the method of fixing the conductors to the insulators and the support of the latter, only a comparatively limited play was allowed, and it was also found that the continued passage of the cars caused a motion of the conductor in one direction. The result of this movement was that a limit of play was reached, and the spring arrangement was unable to maintain the conductor at all in a stretched condition Sagging was produced, which ultimately led to short circuit or a jumping of the trolleys from the trolley wire.

Another system employing a flexible conductor is the Waller-Manville or Simplex system. In this system in its usual form only one conductor is employed. This conductor is not rigidly attached in any way to the insulators, but rests on insulated projecting arms from which it is lifted by the collector-shoe on the car. It is therefore free to move along its length. The conductor is kept in a stretched condition, and all expansion due to temperature variation taken up by means of a powerful straining device consisting of a weight attached direct to the trolley wire By this means any sagging of the conductor beyond that only natural be-

tween the points of support was removed, and the liability of a breakdown from this cause thereby obviated. Owing to the collecting-shoe lifting the conductor off the insulators the latter are subjected to no strains as the car passes them At curves it is, of course, necessary to provide some means to prevent the conductor being drawn into the side of the conduit, and in such positions the arrangement is modified by the employment of insulated arms pivoted so as to allow a vertical movement of the conductor, which falls back into its normal position after the passage of the car. The insulators being placed closer together at curves, sagging due to expansion in the short lengths between them is inconsiderable and produces no difficulty. As a single-conductor system this arrange-

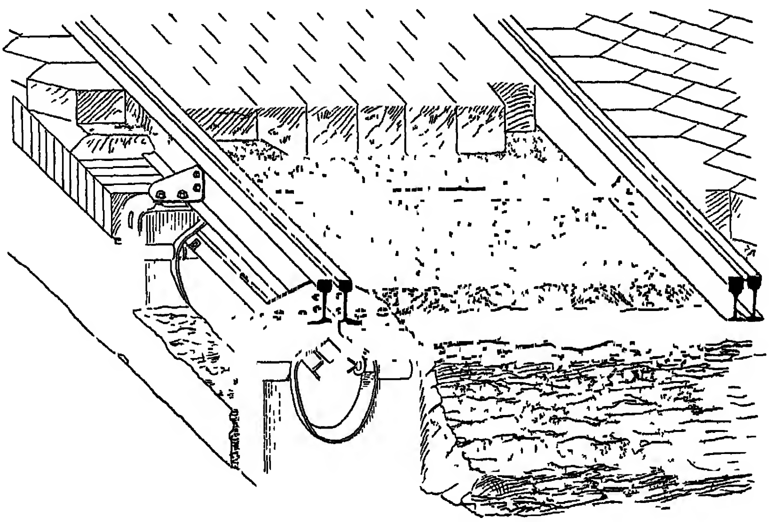


Fig 1127 —Conduit, Buda-Pesth

ment offers in addition the possibility of using a somewhat smaller and shallower conduit, and a consequent reduction in the cost of construction It has, however, never been employed on a sufficiently large scale to afford a satisfactory test under service conditions

The Buda-Pesth system was the first to make use of rigid conductors, and in all the modern lines laid down rigid conductors have been employed, fixed at the central insulating support, sufficient space being allowed at the ends to provide for the necessary expansion

Insulation.—The design and arrangement of the insulators for a conduit system is a problem of no light difficulty As practically all tramway work at the present time is worked at a pressure of from 500 to 600 volts, lower pressures, though they have been employed, may be left out of consideration. The adoption of the lower voltage might render the liability to break down less, but the question of insulating for the above pressures now presents no special difficulties The adoption of even higher pressures might be taken into consideration were it not for the fact that conduit work lines are only as a rule part of a larger system,

and that it would involve the departure from the standard car equipments now on the market, there being objections to the use of more than 500 volts with trolley lines.

As in the course of a longer or shorter time, depending on local conditions, the insulators will become covered with a coating of more or less conducting material, therefore, other things being equal, it is desirable to keep the number of insulators to a minimum. It is also necessary to provide some means of cleaning them

Various methods have been adopted for the support of insulators employed—from the floor of the conduit, from the upper part of the yokes, the slot-rails, or especial fixing in the roof of the conduit Further, they have been either entirely enclosed in the conduit or rendered accessible by means of surface-boxes in the roadway. The method of support from the floor of the conduit has not proved satisfactory, however, as the free passage along the lower portion of the conduit is obstructed thereby, and it is difficult to easily remove dirt and debris collecting round the foot of the support. The latter method, therefore, of supporting from the upper portion of the conduit, is that now generally adopted The question as to whether it is necessary to provide access through the roadway to the insulators appears, however, to be a matter of opinion. As extra space is required in the conduit at the positions in which the insulators are fixed, a recess is formed, into which a certain amount of debris will collect In New York, where the system of fixing a surface-box over each insulator is adopted, these openings are employed partly for cleaning the conduit in addition to providing access to the insulators

In the opinion, however, of Mr A N Connett, who has probably an experience on this subject as extended as any engineer at the present time, the surface-box is entirely unnecessary

A water-jet directed on the insulators by means of a specially-shaped nozzle inserted through the slot is quite sufficient, in all ordinary cases, to remove the dirt and foreign matter which may have collected on them, and the absence of the double surface-box at regular intervals along the whole length of the track very greatly improves the appearance of the roadway, particularly where the side slot is employed The roof of the conduit over each insulator is formed by a steel plate, on which the paving rests The necessity of replacing an insulator occurs only at rare intervals, and in such cases it is cheaper to remove the road-paving for this purpose than to make each insulator accessible On removal of the paving and steel plate, the insulator may easily be got at.

In most systems it has been found possible to keep the number of insulators down to two for each length of conductor-rail The weight of the conductors which the insulators have to carry may vary considerably, in addition, they have to withstand any side strains which may be communicated to them from the plough. Where the conductor-rail is interrupted the end is usually splayed off so as to allow an easy entrance of the plough-shoe, and in order to better sustain the shock at such points, two insulators are usually employed. It is also essential that the conductor-rails should be fixed centrally with the slot, as other-

wise destructive side pressures will be produced. The insulator supports are so designed as to make provision for the adjustment of this in erection.

The weight of conductor-rails may vary up to 25 lbs. per yard, the usual weight being from 18 to 22 lbs., and the design and construction of the insulators is probably one of the most important details in the successful and economical working of a conduit system. The leakage path should be as long as possible in order to secure high insulation, of such a shape as not to become coated with dirt, and at the same time be so designed as to secure the maximum of mechanical strength.

In connection with the subject of insulation, the question of the necessity or otherwise of insulating both conductors again arises. As mentioned above, certain advantages are obtained by insulating one pole only, and using track rails for return circuit.

About the time, however, when the later conduit lines were put down in America, other considerations had become important. Alarming accounts were circulated as to the damage to gas and water pipes which might be expected to occur from electrolysis, especially in the centres of large towns.

As the conduit system in America was a modification of cable tramway construction, it was argued that by insulating both conductors all the dangers of electrolysis would be avoided, and that as the principal cost in installing the system was that of constructing the conduit, the security so obtained would be well worth the extra comparatively small initial outlay. It was also argued that both conductors being insulated, very much greater drop of pressure could be allowed in the return circuit than would be the case where an earth return is adopted. It should, however, be borne in mind that with the heavy track rails now employed a circuit of great conductivity is provided, by the use of which the drop in the return can be reduced to a very small figure, and the saving in energy wasted may represent an appreciable figure in the year's working. Further, it may be taken as fairly proven that, by maintaining the drop in the earth returns within the limits prescribed by the Board of Trade, or, say, at an average not exceeding 4 volts, no bad results need be anticipated from electrolytic action.[1]

In addition to the above, a further difficulty has arisen in various places, in particular in London, in connection with the Greenwich and Kew observatories, owing to the magnetic disturbance produced by stray earth currents and the detrimental effect produced thereby on the work carried out at these institutions.

[1] The weight of the conductor-rail being of the order of about 20 lbs. per yard, and a somewhat better conducting steel being frequently employed for such purposes, the resistance of each conducting rail is approximately equivalent, including bonds, to that of a copper conductor of about 0.23 square inch in section. If, however, the track rails were used as the return circuit, with the heavy rails now employed of, say, 100 lbs. per yard, a return circuit of a conductivity equivalent to about 2.5 square inches of copper is provided, viz. a section of 10 times that of a single conductor-rail. On a long section a considerable voltage drop may occur in the conductors, amounting possibly to 15 volts per rail; the employment of the rail return would enable nearly half of this loss to be avoided, i.e. a saving of, say, 2 per cent of the total energy fed for driving the cars on that section, without in any way exceeding the limits specified by the Board of Trade.

This is, however, too large a question to discuss fully here It is more than probable that the mere laying of tramway track rails is in itself sufficient to divert and disturb the normal flow of the natural earth currents, as was shown at Kew to be the case, and it is certain that the proper and by far most satisfactory solution of this question lies in the removal of such investigations out of the proximity of electric tram-lines.

The significant point, however, in the employment of two insulated conductors lies in the well-known fact that on exposed insulated surfaces a deposit tends to form which gradually reduces the insulation of the negative conductor and brings it to earth potential The author is indebted to Mr. Connett for the results of some tests made in this connection on some of the lines in Washington

A.—INSULATION RESISTANCE IN OHMS

Circuit Number.	October 17		November 15		December 6	
	Positive	Negative	Positive	Negative	Positive	Negative
1	19,500	770	8300	400	36,800	1250
2.	16,500	280	5200	14	25,800	700
3	18,100	670	8000	480	29,100	830
4	10,900	770	5200	330	27,600	910

B.—TESTS ON CIRCUIT NO 4

Date	Resistance East Conductor	Polarity	Resistance West Conductor	Polarity	Remarks
Dec 6	27,600 ohms	+	910 ohms	−	Reversed after test
Dec 24	280 "	−	2500 "	+	
Jan 9	5000 "	+	780 "	−	

Table A gives the insulation resistance in ohms of four separate circuits on three separate dates, from which it will be seen that the insulation of the positive conductor averages more than twenty times that of the negative, the negative insulation varying from about 70 to 300 ohms per mile

Each of the four circuits consists of approximately 4 miles of conductors, each supported by, roughly, 1500 insulators

The differences on the different dates are probably due to the state of the weather, October 17 being dry; November 15 hard rain, and December 6 dry and cold, with no rain during the previous week. The exceptionally low reading of the negative conductor of No 2 circuit on November 15 was due to a local fault in a rubber-connecting cable at a crossing.

In order to ascertain whether this difference was due entirely to

this question of polarity, the polarity of one of the circuits was reversed, the results being given in Table B

The question therefore arises whether any real result is obtained by placing an insulated negative conductor in the conduit.

In actual working, however, earths are likely and do occur from other causes, both in the insulation of the conductors and in the ploughs, and in order to meet the difficulties produced thereby it has been found necessary to divide conduit tramway net-works into independent sections. Special arrangements are made at the switch-board so that the polarity of the feeders, which are connected to and supply these sections, may be reversed at any time. In order to keep the insulation of both conductors in a uniform state of efficiency, it is usual to reverse the polarity at regular intervals, usually about once every three or four weeks This device makes it possible at any time to connect a conductor of which the insulation is faulty to the negative pole, and in the event of either pole in a plough or car equipment going to earth, to keep the polarity of the conductors of the section on which the car is placed so that the fault on the car or plough is kept on the negative side of the system, thereby avoiding a short circuit (It is clear, of course, that this cannot be done if a faulty car earths the insulated side of a faulty section of line) The whole argument in favour of double insulated, and the possibility of using unipolar conductors, practically turns on the question that, where two are employed, although one of them is for all practical purposes at earth potential, in the event of the break-down of the positive conductor the polarity of both may be reversed, and a complete reserve is thereby provided[1] Otherwise the advantages are all in favour of the single insulated systems, and it simply remains a question as to the possibility of designing a unipolar system giving the necessary freedom from break-down without introducing other objectionable features. This point is raised further in connection with mixed systems

This point also has a bearing on the insulation of car equipments It must be borne in mind that it is possible that the car may have to run on a section in which either, *i.e.* + or −, pole may be earthed It is therefore necessary that the whole equipment should be capable of standing the full line pressure to earth

With the trolley system, in which the negative pole is earthed, the magnet coils are usually at the earthed end of the circuit, and are therefore only subject to a pressure corresponding to the drop in voltage through them, but under the above circumstances they may be subjected to practically the full line pressure. The same remark applies to electromagnetic brakes should they be employed.

Design.—The conditions which have to be considered in designing a conduit are comparatively simply stated They are.—

(1) The provision of suitable arrangements for the efficient draining of the same, and for the removal of foreign matter collected in the conduit.

(2) The design of the conduit tube itself so that it has ample strength

[1] In the opinion of the writer the same advantage would be secured by a double unipolar system, while many difficulties of the double insulated system would disappear

to resist the crushing strains due to traffic or the strains tending to close the slot due to any expansion of the pavement.

(3) Reasonable accessibility for the replacement if not for the inspection of insulators, conducting rails, and their fixings.

All these are simply questions of design, and present no very special difficulty where the track is simple As soon, however, as it is necessary to deal with points and crossings a number of further difficulties present themselves

The material used in construction of the conduit tube adopted in all modern installations consists of concrete, which forms the bottom and walls of the tube. In this at regular intervals are embedded cast-iron or cast-steel yokes, which carry and hold in position the rails forming the slot and the roof of the conduit.

The insulators, as mentioned above, may be fixed in various manners in some of the early systems, for example, the Love and the Bentley-Knight, the insulators were attached to the yokes, the more modern practice is to attach them to the under side of the slot-rail.

It is obvious that at crossings two conduit tubes will intersect, and at such points four overhanging corners occur which have to be correspondingly strengthened Sufficient strength for this purpose, however, is obtained by placing the yokes as close as possible to such a crossing point and bolting the slot-rails together. On the other hand, in the construction of a point this difficulty is very considerably increased, as a long centre tongue in the track paving has to be efficiently supported in such a manner as to leave sufficient section in the conduit for the passage of the plough, the conductor-rails being interrupted in such positions Steel constructions are usually employed for this purpose, and the cost of this special work is one of the most expensive items in the construction of a conduit line

Centre versus Side Slot.—The lines constructed in New York, Washington, Nice, and Bordeaux, and the new lines of the London County Council, are built with the slot in the centre of the track In some cases, however, the local authorities have objected to the centre slot, as in Berlin, Brussels, and Buda-Pesth, consequently in these places, as also on the line recently constructed in Bournemouth, the slot is formed in the groove of one of the track rails. This latter arrangement has the advantage that the third set of rails is avoided, and if no inspection-boxes are placed over the insulators, the line presents a similar appearance to that of an ordinary horse tramway, it being practically impossible to see the slot unless the individual is standing almost vertically over the slot-rail

This would appear at first sight to be the ideal solution for a conduit system, various other considerations, however, soon present themselves First, the conduit being under one of the track rails, it is obvious that this will have to be constructed of sufficient strength to carry the maximum weight due to a fully-loaded car, which, with those in use at the present time, may easily amount to 3 tons per wheel, which is considerably greater than the loads carried by ordinary traffic, which are not likely to exceed $1\frac{1}{2}$ to 2 tons per wheel.

For the same reason it is desirable that that slot-rail, which in this case

is also the rail wheel, should have a vertical web, and this has the effect of reducing the distance between the slot-rails at their base, thereby confining the construction of the plough A more important objection is that the wheel flanges throw mud and dirt on to the plough, thereby tending to reduce the insulation of the same. Where a single conductor conduit is

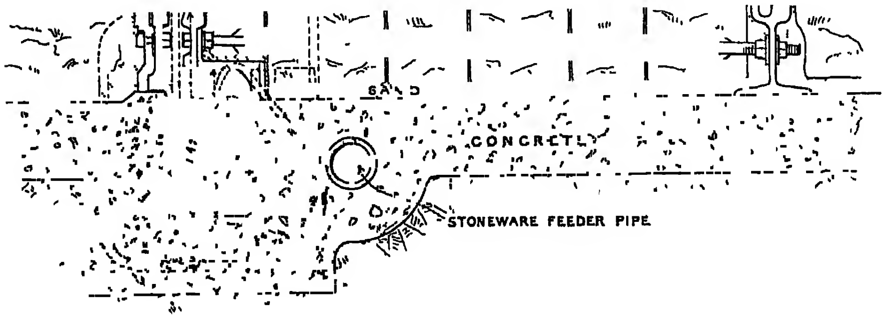


Fig 1128

employed, as in the Simplex (or Waller-Manville) system, it is quite possible to arrange the track slot-rail with a vertical web in such a way as to be supported during its whole length upon the outer wall of the conduit, the single conductor being placed in the conduit under the slot rail on the inner side of the track (see fig 1128) In an unsymmetrical conduit of this type the wheel-rail is fully supported, and the insulated

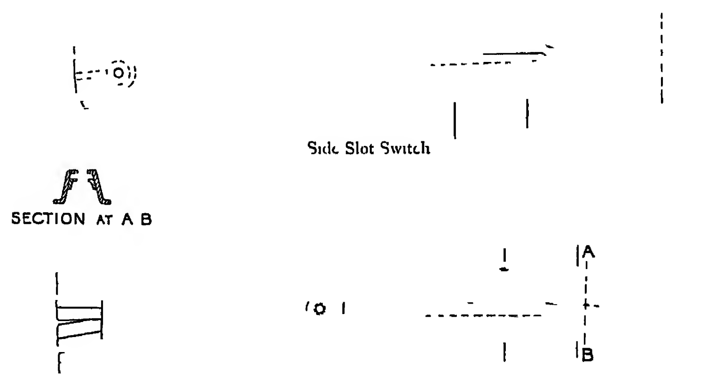


Fig 1129

collecting-shoe being out of line with the slot will not suffer from mud or water thrown to the same extent.

The inherent difficulty, however, of the side slot is the point

With the centre slot a comparatively light movable tongue can be used to guide the plough, but in the case of the side slot the tongue will have in one position to deflect and carry the car wheels, requiring therefore to be much stiffer and stronger in order to carry the strains involved, and

necessitating the surface over its whole length being flush with the roadway. Further, where only the plough has to be deflected, the angle of the point may be made much more blunt, and the length of the tongue and corresponding overhang is consequently considerably reduced (fig 1129)

In order to avoid this disadvantage in point construction with the side-slot system, it is proposed to divert the slot to the centre of the track at points, thereby leaving the track points the same as with an ordinary tramway track. This arrangement has been adopted in Paris, as shown in figs 1130 and 1131 Where this arrangement of diverting the slot to the centres is adopted with a side-slot conduit, it follows that the number of points which would normally occur with a centre-slot system is increased to the extent of the points where the slot turns out from the side to the centre, *i e* one extra for every branch.

Where points occur it is obvious that the plough must be guided to take

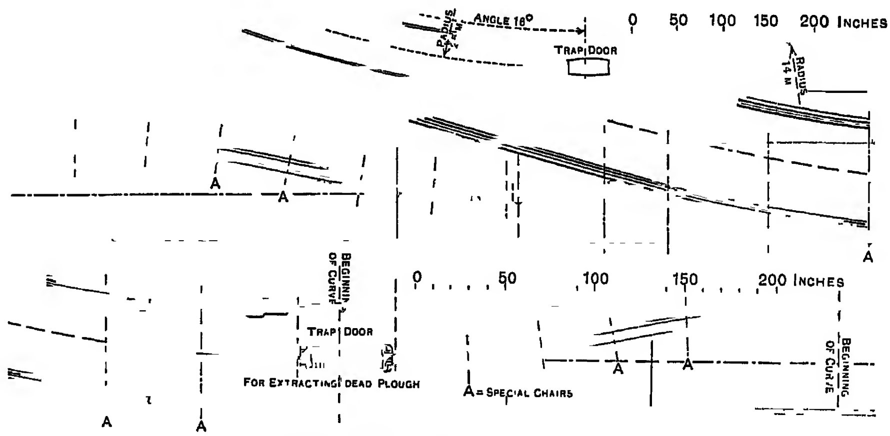


Fig 1130 —Deflection of Side-Slot to Centre-Slot

the same path as the car, failure in this respect is one of the sources of break-down to which conduit systems are liable Serious accident, however, can be guarded against if the plough is free to move on a slide passing the whole width of the car, so that in the event of plough and car taking opposite roads the plough can travel along the slide (and either fall out or move clear of the car; this, however, is seldom likely to occur, as the driver will probably notice the failure before this happens and reverse his car)

With a centre-slot conduit in addition to the track points it is also necessary to provide a point in the slot rail to direct the plough in the same direction as the car All three points are usually controlled together by means of a single lever (fig 1132) With the centre-slot it is possible for the car and plough to take different directions should, for example, the slot tongue become jammed. With the side-slot, on the other hand, the plough is bound to take the same direction as the car, and in so far this is a distinct advantage in favour of the side-slot

On the London County Council tramways, which have adopted centre-slot, the point construction is of special interest owing to the novelty of the

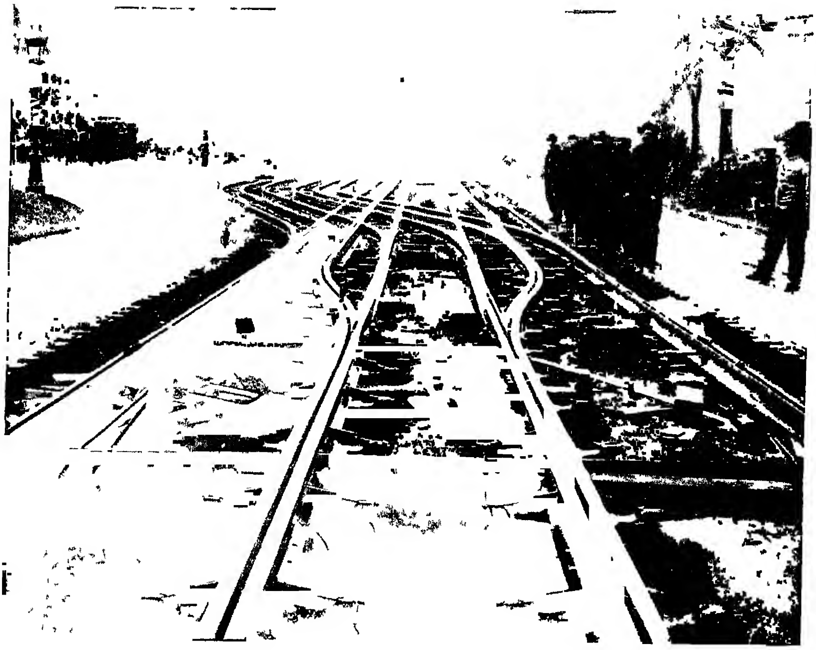


Fig 1131 —Deflection of Side Slot to Centre-Slot

Fig 1132 —Single Switch Controlling Track and Slot-Tongues

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CONDUIT CONSTRUCTION

design. It might be described as a movable slot instead of a movable tongue. The details are shown fully in fig 1133 It was considered necessary that the width of opening on the surface of the street at these points should not exceed the normal slot width of $\frac{3}{4}$ inch This necessitated the slot points having two levels, that is, from the heel to the fixed point being flush with the surface, and from that point on being underneath the head of the slot-rails and of the fixed point. This does away with the objection of extra width at the end of the fixed point, but it adds difficulties due to having slots on the back of the slot-tongues where they are flush with the street It will be noted that these slots are corrugated In working, care will have to be taken that these slots do not fill with dirt, pebbles, or other

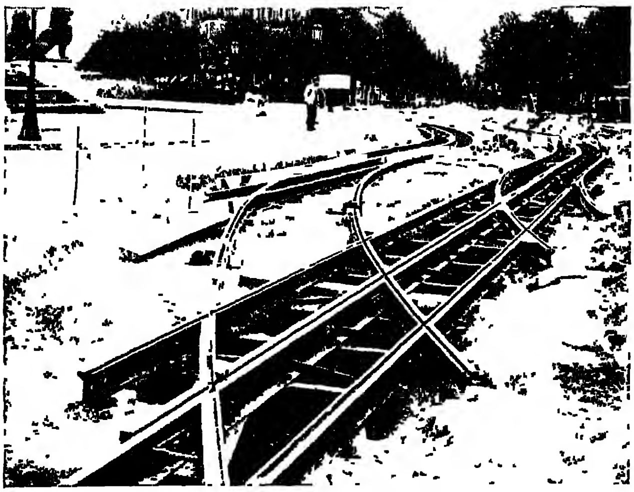


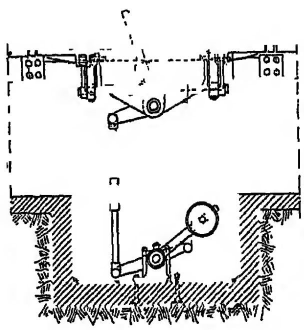
Fig 1134 —Siding without Conduit, Paris

hard matters, as otherwise the proper working of the apparatus would be in danger.

Most of the accidents with the slot system occur at points, and the above arrangement of bringing the conduit to the centre of the track reduces the probability of accidents from this cause to a minimum, as the only possibility is that of the plough striking the tongue in the central position In all such positions it is advisable to provide a trap for the removal of faulty ploughs

Several forms of traps have been designed for this purpose, but that shown in fig 1135 fully meets all the requirements. It is operated by means of a lever after the car has reached its position. The arrangement of the mechanism is readily seen from the drawing. The trap is opened by throwing over the lever, counterweights being provided to reduce the effort required for doing this as much as possible

It may be concluded, therefore, that *provided that the mechanical weakness of the side-slot point can be overcome*, the side-slot would ordinarily be the more certain arrangement, as the car would force the tongue into a definite position.



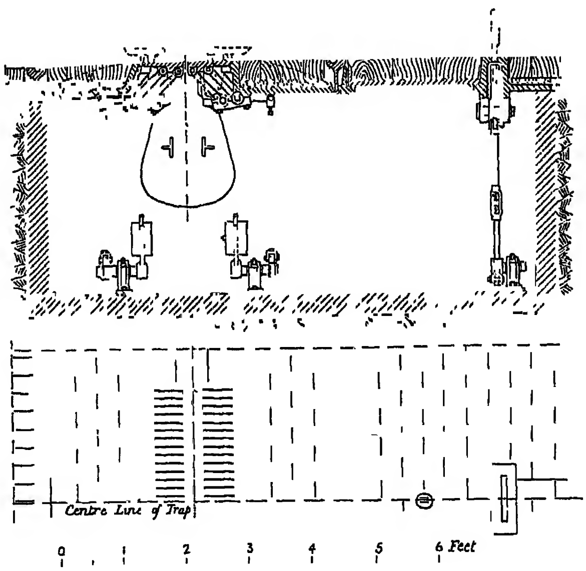
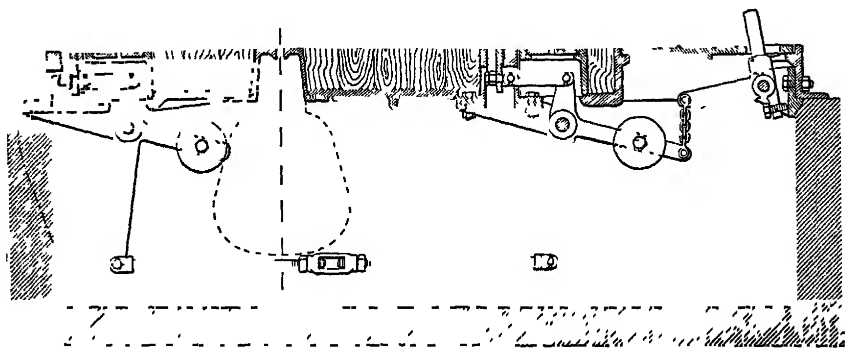
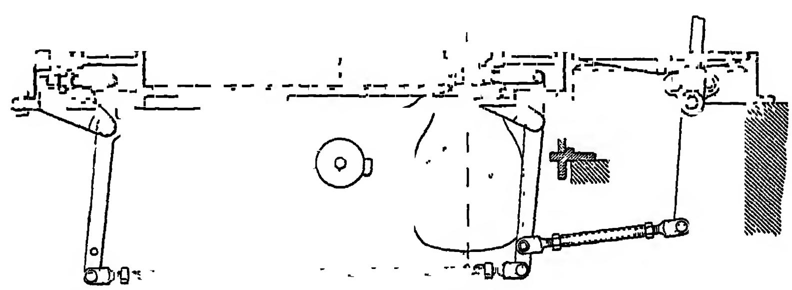


Fig 1135 —Trap-Door Mechanism for Plough, operated after car has reached its position (Bastille-Charenton Tramway)



A, For Centre Slot



B, For Side-Slot

Inches 12 6 0 1 2 3 4 5 Feet

Fig 1136

It is different, however, for example in a mixed system, where an overhead line branches off from a conduit section. In such a case it is possible that, owing to a false setting of the tongue, the car should take the overhead branch, with the result that the plough would jam in the point, giving rise to a serious accident In such a case precautions should always be taken of using a counterweight mechanism (see fig 1136), so designed that the track should always be open for cars running on the conduit system, but in view of possible accident it is still safer to adopt the above-mentioned device of diverting the conduit to the centre of the track

In connection with the question of side-slot lines a further point arises as to whether the slots should be on the same side, the inside or the outside of the tracks Where the plough is suspended from a sliding arrangement enabling it to travel freely the full width of the car, this becomes quite immaterial from the point of view of the designer, and in such a case placing the slots on the two inner track rails will have the advantage that the slot-rails will be at the highest part of the roadway, and will have nearly all road matter swept away from them In either of the other arrangements, one or both of the slots will be liable to have a considerable portion of the road sweepings swept into them

This arrangement has the additional advantage during construction that it confines the deeper excavation work to the centre of the roadway, and if it is possible to take in hand the construction of the full width of the track at one time, it allows both conduits to be put in together

CHAPTER IV

DETAILS OF CONSTRUCTION

In the New York and Washington systems the yoke is of the type shown in fig 1137, that is, in addition to the central position forming the section of the conduit and carrying the slot-rails, the yokes have an extension on each side carrying the track rails, and to which the latter are bolted.

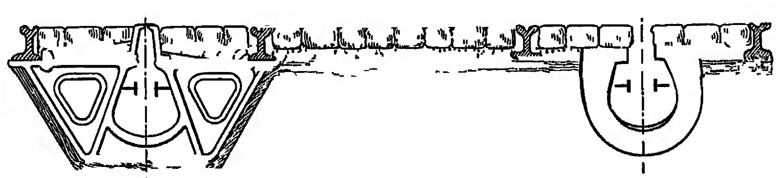


Fig 1137 —Washington Tramways (Metropolitan Railroad Co)

This construction was inherited from the cable conduit, and a similar arrangement has been adopted in other places with centre-slot. Where, however, as is usual in this country, a good foundation of concrete of from 7 to 9 inches in depth is laid under the full width of the track, these extensions

of the yokes are unnecessary, as the track is sufficiently solid without them

There may possibly be some convenience during construction to put in the full-track-width yokes, say two for each rail length, in order that the whole of the iron-work may be bolted up solidly together before the concrete is put in, but as this idea does not appear to have been adopted, the advantage gained is probably not worth the extra cost of the yokes

The first question which is involved in designing the yokes is the depth of the conduit. This depends, in the first place, on the size, section, and weight of the conductors it is intended to adopt, the insulators to be employed, and the method of fixing same, also to a certain extent on the class of paving to be used, as this latter point determines the depth of the slot-rails

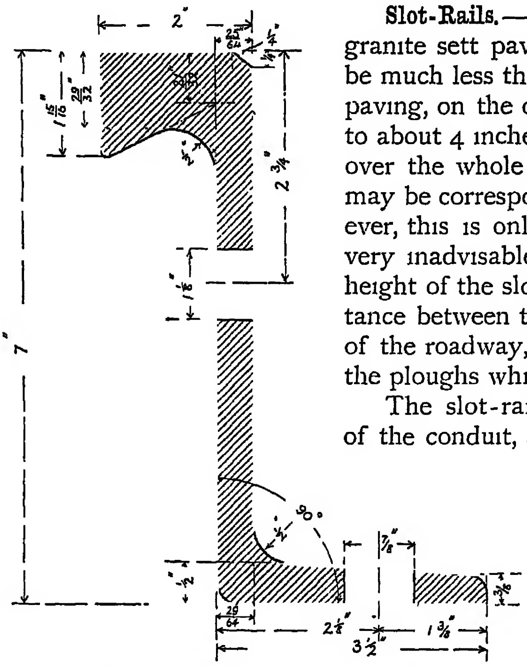


Fig 1138 —Section of Slot-Rail, 60 lbs per yard

Slot-Rails.—*Depth of Slot-Rails* —With granite sett paving the slot-rail depth cannot be much less than 6 to 7 inches, with asphalt paving, on the other hand, it may be reduced to about 4 inches, and if this latter is adopted over the whole system the depth of conduit may be correspondingly reduced, where, however, this is only partly possible it would be very inadvisable to vary on this account the height of the slot-rails, which involves the distance between the conductors and the surface of the roadway, owing to the complication in the ploughs which this would introduce

The slot-rail forms in reality the crown of the conduit, and as it has therefore to be sufficiently strong to carry the weight of any road traffic which may pass over it a certain minimum strength is necessary, but the actual depth, as above-mentioned, is really determined by the class of paving to be adopted

As regards the width of the head of the slot-rails, from considerations of traffic it is desirable that these should be kept as narrow as possible, on the other hand, it is necessary to provide a sufficient space below the head in order to accommodate the nuts of the tie-bars which connect the slot-rails to the yokes and hold them in position. As these tie-bars are of necessity run at an angle to the vertical, these nuts will not lie flush on the inner surface of the slot-rail, but would be required to be supported by a bevelled washer, and the head of the slot-rail has to be of sufficient width to cover these and at the same time allow sufficient clearance for the passage of the plough.

In the construction adopted on the London conduit system this width has been reduced somewhat by the device of putting in a bend in the tie-

bar just before passing through the slot-rail, the web of the rail being vertical (See fig 1139.) Experiments made on these bars show that it requires about 11 tons to straighten them, and that the breaking strain is about 13 tons, showing that the disadvantage of introducing this bend is by no means serious.

Fig 1138 shows a section of the slot-rail. The two rails are set so as to make the slot $\frac{3}{4}$ inch in width, and the surface so as to be $\frac{3}{8}$ inch higher than that of the wheel-rails

In order to prevent the water which may find its way through the slot

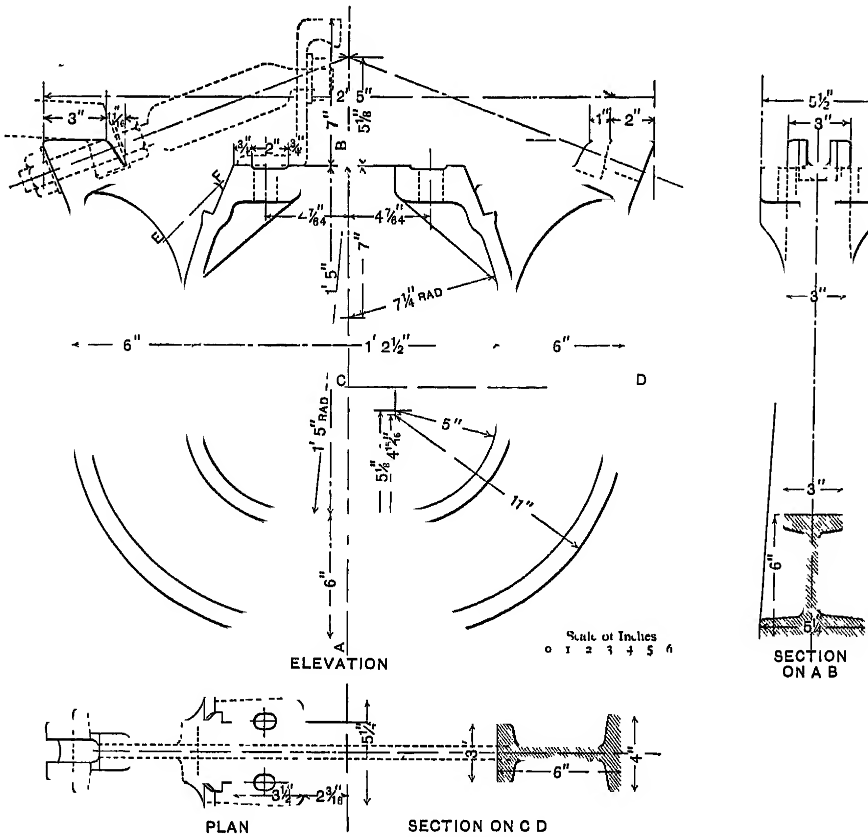


Fig 1139 —L C C Yokes

running over the roof of the conduit and falling on to contact-rails and insulators, a lip is provided either at the lower inner corner of the head of the slot-rail, as in the section shown, so as to drop this straight down between the conductor-bars, or at the inner edge of the base

Width of Slot—The width of the slot is much more important with centre-slot systems than with side-slots, where a rail groove of $1\frac{1}{16}$ to $1\frac{1}{4}$ inch already exists. Where the side-slot is adopted in this country it is probable that the bottom of the groove will be narrowed by a lip on one

of the slot-rails, reducing the slot to about $\frac{3}{4}$ inch, as in the centre-slot system.

An all-important consideration in large towns is to reduce, however, the depth of the conduit as much as possible, so as to reduce to a minimum the outlay which it may be necessary to make in shifting heavy gas and water pipes from beneath the track, the cost of which work may involve in some cases very great expense Indeed, in London and Glasgow, and no doubt in other places, there are many points where railways, &c, pass under the roadway, in which it is not feasible to raise the level of the roadway, and where there is actually not sufficient space to allow of the construction of a 2 feet 6 inches conduit

Also, in order to prevent any closing of the slot due to the expansion of the paving, the yokes have to be sufficiently strong to resist any strains that may occur, and it is obvious that any increase in the conduit depth will considerably increase the weight of the yokes necessary to ensure this

Detailed dimensions of the yokes which are being employed on the L C C tramways are given in fig 1139, the design being an extremely simple one The general form of the yoke is similar to the letter U The top of the yoke is provided with a seat for the slot-rails to which they are bolted, and also with a lug for the tie-bars. There is, in addition, a seat for a plate which comes at the bottom flange of the slot-rail, to prevent the comparatively weak corner of concrete there from breaking away The yokes are spaced every 3 feet 9 inches from centre to centre This comparatively close spacing of the yokes has the advantage of not requiring an inordinately heavy yoke, and at the same time making a better provision against the danger of slot closure by pressure on the slot-rails between the yokes. Vertical and horizontal sections are shown to the right and below respectively

Taking the average mean cross-section of these yokes approximately, *i e.*—

Width of top flange	3	inches
Width of bottom flange	4	"
Thickness of flanges	$\frac{3}{4}$	"
Thickness of web	$\frac{5}{8}$	"
Total height over flanges	6	"

the moment of inertia will be roughly—

$$I = 44{\cdot}2 \text{ (inch-pound) units.}$$

Taking E at, say, 20,000,000, and L at, say, 31 inches, and using the relation

$$d = \frac{W L^3}{3 E I},$$

we get for the deflection for the half yoke, on an assumption of a strain of about $2\frac{1}{2}$ tons, about 0·062 inch, or, say, $\frac{1}{8}$ inch for the whole yoke

In view of the fact, therefore, that the yokes are firmly bedded in the walls of the conduit, that granite setts are used between the tracks, and that the greater portion of the strain produced by any pavement expansion

would be taken up at the track rails, the bases of which have a good setting in the concrete foundation, there would seem ample margin of strength to keep the closing of the slot width very much within the above calculated figure

Clearance below Conductor-Rails.—Experience has shown that it is desirable to have a clear depth of not less than 6 inches, but preferably somewhat more, between the under side of the conductor-rails and the floor of the conduit, in order to readily carry off any water or other debris which may find its way into the conduit without making contact with the conductor-rails

Where the conductor is only cleaned periodically it is desirable to have much more, say 8 inches at least In cases where the gradients of the side streets or the conduit line itself are likely to lead, in the event of very heavy rainfall, to flooding of the line, this contingency can best be provided against by decreasing the distance between the drainage pits rather than enlarging the size of the conduit channel

Unless special reasons exist for reducing the conduit depth to an absolute minimum, the space below the conductors may therefore be taken at 7 inches

Height of Conductor-Rails.—In determining the distance of the conductor-rails from the road surface, in addition to the depth of the slot-rails, sufficient clearance has to be allowed for air insulation, and the limiting dimension in this respect is that between the top of the conductor-rails and the under part of the yokes seat (see fig 1139)

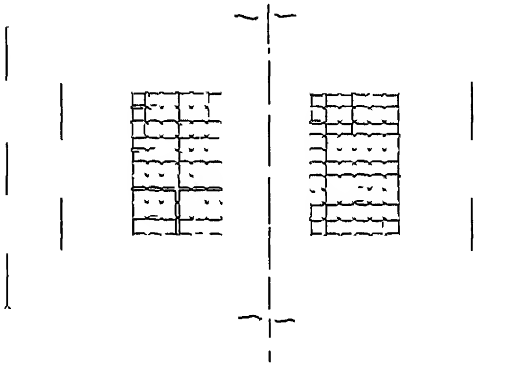
This distance should hardly be less than $2\frac{1}{2}$ inches, which, with $1\frac{1}{2}$ to 2 inches in the yoke seat itself, gives 4 to $4\frac{1}{2}$ inches between the top of the conductor-bar and the under side of the slot-rails, or with a 7-inch slot-rail 11 to $11\frac{1}{2}$ inches from the surface of the roadway to the top of the conductor-rail as the *minimum* distances

The actual distance is, however, determined largely by the method of fixing the insulator, by which this minimum distance will probably be somewhat increased.

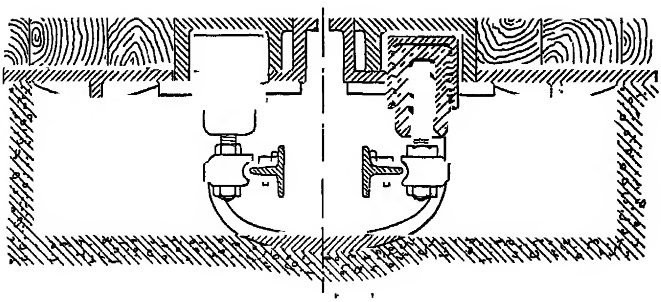
Assuming, however, that the insulators can be fixed to support the rail at this height, and a conductor-rail $3\frac{1}{2}$ inches deep, we obtain on the above basis for ordinary purposes $7 + 4\ (\frac{1}{2}) + 3\frac{1}{2} + 7 = 21\frac{1}{2}$ to 22 inches as the minimum depth of the conduit for ordinary construction

If the height of the slot-rail can be reduced below the size above given, and in special cases for short distances (as in crossing railway bridges) the free space in the conduit below the conductors is also reduced, the minimum conduit depth may be still further lessened accordingly, but, generally speaking, the above represents the minimum depth which it is advisable to employ

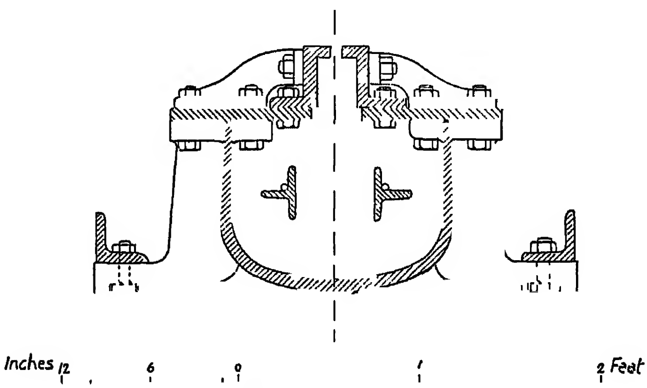
There are cases in which this depth has of necessity had to be reduced, as, for example, at the Pont de l'Alma, Paris, where the conduit depth has been reduced to as little as 15 inches, leaving only about $3\frac{1}{2}$ to 4 inches below the conductor-bars The plan and two sections of this piece of conduit are shown in fig. 1140, but in this case the whole conduit has been built of iron, the total depth being 17 inches. The cost of construction in



Plan



Section of Insulator



Section at Casting

Fig 1140—Special Shallow Conduit, Pont de l Alma, Paris

such cases is certainly increased, while special precautions have to be taken to keep the channel clean.

Width of Conduit.—The conduit width depends on the width of the conductor-rails, and the distance between them plus the air-space necessary for insulation purposes In the L.C.C. conduit this amounts to $14\frac{1}{2}$ inches.

With conductor-rails of opposite polarity it is hardly possible to reduce this, but were a unipolar system to be adopted, or in particular a single conductor system, there is no doubt a reduction is possible.

In the Waller-Manville system, where a flexible conductor is employed, the width is reduced to about 7 inches (see fig. 1141).

It has also been suggested that a $4\frac{1}{2}$-inch slot-rail might be used (instead of 7-inch rail) with granite paving, 3- or 4-inch blocks being used against the slot-rail, and 6-inch setts beyond; but this does not seem to meet the approval of road surveyors, owing to the difficulty in keeping the setts next the rails firmly fixed and in good order It is more permissible with a side than a centre slot, as the latter splits up the paving between the tracks to two strips of only 2 feet 1 inch to 2 feet 2 inches in width, thereby interfering with the bonding of the setts.

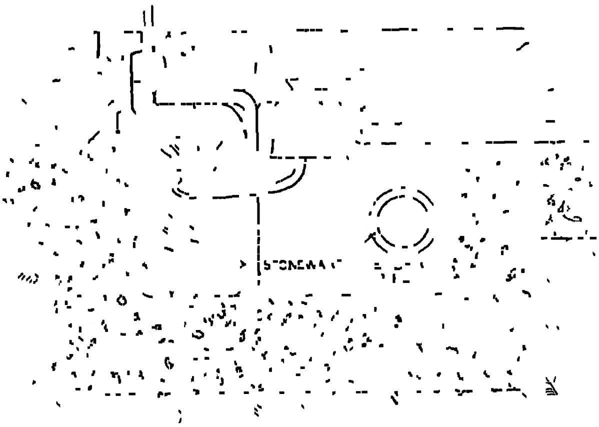


Fig 1141 — Cross Section of Conduit at Hatchway, showing Carrier-Arm and Collector

Conductor-Bars.—In the above calculation the depth of the conductor-bars was taken as $3\frac{1}{2}$ inches It might in some cases be reduced, but it must be borne in mind that the surface of contact has not only to have sufficient conducting area, but also a good bearing surface so as to suffer no appreciable wear

Contact may be made either vertically or horizontally The form of conductor now most usually employed consists of a T angle-iron turned sideways ⊣ ⊢, the flat heads being turned inwards and forming the working contact surfaces.

Other forms have, however, been used, the shape depending on the method of making contact with the bars. · This point is treated more fully in connection with the ploughs construction, but in Brussels the contact is made on the top of the rail, while in the old Blackpool conduit the conductors were oval in shape

Copper conductors have been used at Blackpool, and in some other instances. Copper has, of course, a much greater conductivity than iron or steel, but, on the other hand, it does not wear so well, and the section provided to secure good working contact and bearing surface is in most

cases quite sufficient, when steel is employed, to carry the current without excessive drop

Further, owing to the advisability of subdividing the line into half-mile sections, on account of the security it gives in dealing with possible insulation faults, the employment of copper conductors loses what slight advantage it might have had. Where the line has not been sectionized in this way, and it has been found necessary to increase the carrying capacity of the conductor-bars, this can be more cheaply done by laying

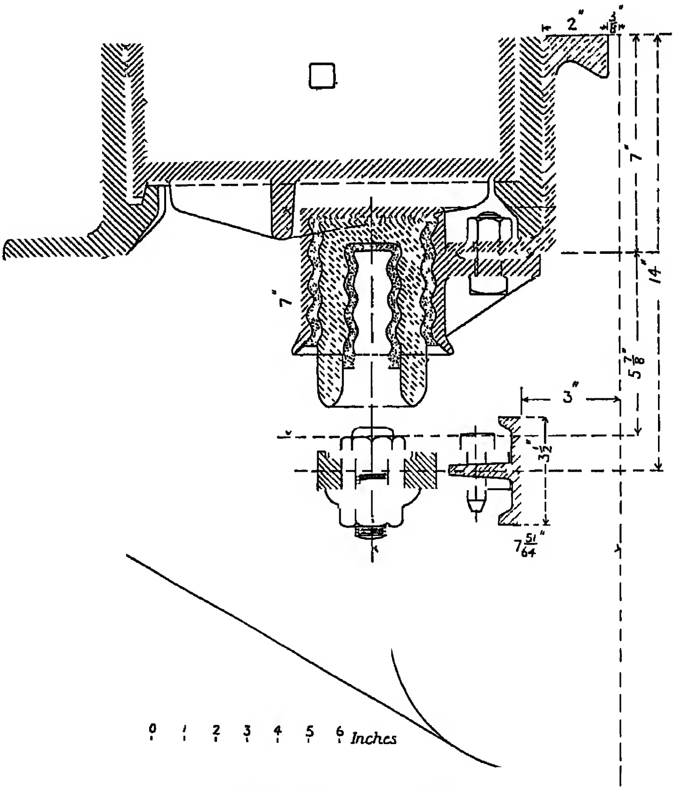


Fig 1142 —Clip for Conductor-Bar

a copper cable of suitable capacity at the back of each conductor-bar, than by using copper conductors Cables are laid in this manner in Paris, and are shown in fig 1140 They are electrically bonded at sufficiently short intervals to the steel conductor-bar to prevent any possible electrolytic action between the two metals

The material which has proved itself most suitable up to the present time is mild steel, which has a carrying capacity about $\frac{1}{10}$ of that of copper, or, speaking generally, the drop (per mile) is given by the formula

$$v = 0.4 \times \frac{A}{B},$$

where B denotes the sectional area in square inches, and A the current in amperes

It has generally been the practice to make the conductor-rails of the same length as the slot-rails, mainly for the purpose of enabling the joints in the slot-rails and the conductor-rails to be reached through the insulator inspection-boxes fixed at these points, which in some cases were very large.

Where no insulator-boxes are fixed, or where the insulators are not fixed at the joints in the slot-rails, there is no special object in having them this length Their *length* should, however, *be a multiple of the distance between the yokes*, so as to allow of the proper spacing of the insulators.

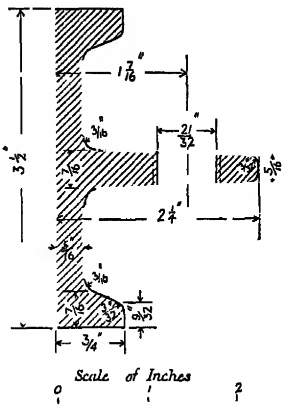


Fig 1143 —Conductor Bars, 22 lbs per yard

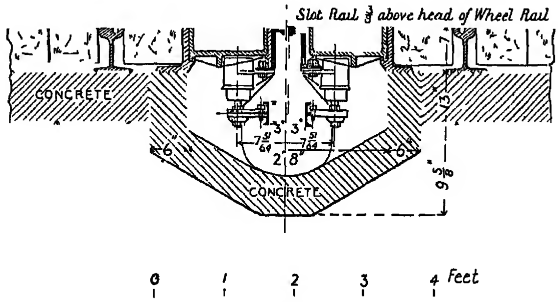


Fig 1144

The conductor-bars at present being employed by the London County Council have the section shown in fig 1143, weigh 22 lbs per yard run, and have a resistance of about 0 18 ohm per mile each

The conductor-bar is firmly attached to the stalk of the insulator by means of a clip, which is clearly shown in fig. 1142

The rails are made in lengths of 30 feet, and are supported by insulators fixed one in the middle of each, and one at the junction of each two rails. The bolts holding the rail to the insulator in the centre are fixed rigidly, those at the ends pass through holes in order to allow for the rail expansion, the rail-ends being connected together by double copper bonds.

At the ends of sections, and at points and crossings where gaps occur, two insulators are fixed, to give additional mechanical strength

CHAPTER V

INSULATORS

Fixing of Insulators.—Various arrangements have been adopted for fixing the insulators in position They may be divided under three classes The oldest plan, employed in most of the earlier conduits, was that of fixing the insulators to the yokes. This method, however, has been

abandoned owing to the necessarily confined space available at these points.

A second method of fixing was tried in New York, namely, that of supporting the insulator at the top of a pillar from the bottom of the conduit. This method has, however, the disadvantage that it places an obstruction in the free channel of the lower part of the conduit, and gave rise to difficulties in cleaning.

By fixing the insulators between the yokes it is possible to enlarge, without difficulty, the width of the conduit in these positions, and leave room for the employment of a large and efficient insulator. They are fixed in position either by bolting direct to the slot-rails, or by being fitted into insulator-boxes which are in turn bolted to the rails. Both these latter methods have been employed in comparatively recent constructions See figs. 1145 and 1146.

As mentioned above, there is a minimum height between the top of the conductor-rail and the surface of the roadway, and, as will be seen presently, a minimum height is required for the insulator. This height is greater than the space available between the horizontal web of the conductor-rail and the under side of the slot-rails, so that in the event of it being necessary to keep the conduit depth an absolute minimum, the top of the insulator will of necessity be above the bottom of the slot-rail, in fact within about 2 inches of the surface of the roadway The adoption of this construction therefore renders the employment of a road-box for carrying the insulator imperative, as it is not possible to use the ordinary paving over the top of the insulator, this is quite apart from the question as to whether it is considered necessary to provide inspection-boxes for the insulators or not. Fig 1145 shows an insulator of this class

In places where the use of these road-boxes is objected to—and it must be admitted that the absence of these boxes, two at intervals of say every 15 feet, greatly enhances the appearance of the roadway—it becomes absolutely necessary to sink the insulators, and in such cases it is usual for the insulators to be bolted to the under side of the slot-rail, as in fig 1146

Instances of both these constructions have been put down in this country, the lines of the London County Council being constructed with surface boxes, the lines laid down in Bournemouth without. Fig 1142 shows the design of the London County Council insulator, which is fixed direct to the slot-rail independently of the road-box.

Design of Insulators.—The primary considerations to be borne in mind in designing the insulators are those of insulation and mechanical strength.

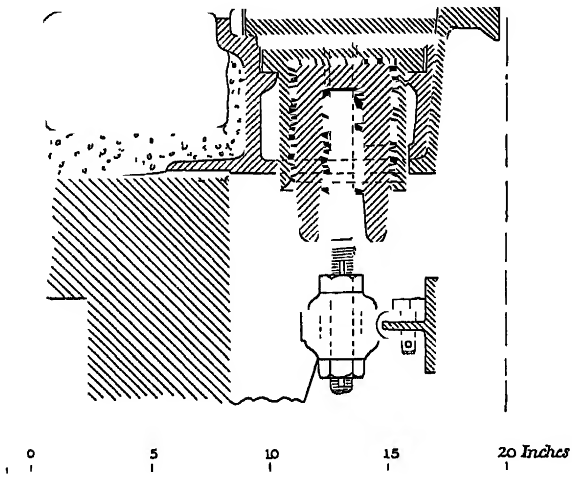
Insulation.—As in most systems the insulators are fixed at distances of about 15 feet apart, it follows that there will be for each conductor about 350 per mile, or a total for both conductors, on a system of 10 miles of conduit, of not less than 7000 insulators The design of an insulator which shall be thoroughly effective, and which shall maintain its insulation under the conditions of conduit working, is therefore very important That this problem has, however, been thoroughly and satisfactorily solved may be seen from the figures given on page 166. Even assuming that the insulation of *both* conductors was no better than that of the negative,

the total leakage per mile would not exceed $\frac{1}{6}$ ampere, or amount to more than 20 units per day on a 10-mile system, quite a negligible quantity.

The insulators employed on the first line installed in New York were built up of mica, &c, round a central bolt; they failed, however. In Brussels the insulating material employed is an india-rubber composition, which has on the whole proved fairly satisfactory. It has the disadvantage, however, of being expensive, and deteriorates in the course of time by exposure to the atmosphere.

The material which has proved itself thoroughly satisfactory is porcelain, and there is no reason that can be urged against its employment

From the circumstances of the case it is only natural that the insulators should be liable to become covered with mud and dust, and for this reason



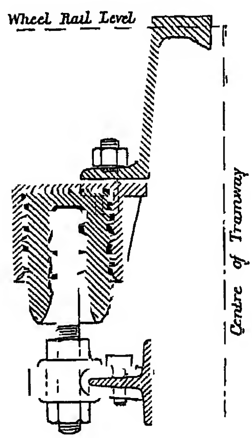


Fig 1145 —In Washington Fig 1146 —In Paris

Central Conduit Insulators and suspended conductor-rails

the insulating surfaces should be as far as possible vertical or inverted The most satisfactory shape is a type of "petticoat insulator", in which the central bolt projects underneath and carries the rail, while the whole of the upper portion is enclosed in a metal cap, provided with a lug or lugs for bolting the insulator in position, and a cape for throwing off any water or mud which may fall on it

The central bolt is fixed in the insulator, and the insulator in the cap, by means of Portland cement, the opposing surfaces being corrugated in the manner shown in the drawings.

Mechanical Strength of the Insulators.—The insulator must be sufficiently strong to carry, first the conductor-rail, and also to provide against any stresses produced by the passage of the contact-ploughs.

In order to avoid, therefore, any possibility of the insulators becoming broken in ordinary work, and of having to replace them, even where they are rendered accessible by surface boxes, it is advisable to provide an ample margin of safety.

Where T conductor-rails are employed, the rails being in lengths usually of 30 feet and weighing about 20 lbs. per yard, the weight of rail to be borne by each insulator will be about 100 lbs; the pressure exerted by the plough contacts in this case will probably not exceed 3 to 6 lbs, this pressure being, however, usually in a direction at right angles to that of the weight These forces act at a point which is probably some 3 to 5 inches away from the axis of the insulator

A drawing of the insulator at present being employed on the lines of the London County Council is shown in fig 1142, page 180. It is bolted direct to the slot-rail, and placed sufficiently low down to enable the box cover to be sufficiently deep to take granite setts

Figs 1145 and 1146 give sections of the insulators used in Washington and Paris, in the former the insulator is accessible by a road-box, and is probably fixed as high as possible, in the latter, the insulator is entirely below the slot-rail, and probably represents the minimum advisable dimensions, both for securing mechanical strength and providing sufficient length of insulating surface The height of this insulator is 7 inches, or including the length of the stalk, 12 inches

Provision is made in the lugs of the cap of the insulator so as to allow some slight adjustment in a direction parallel to the conductors, while the clip to which the conductor itself is fixed has a slotted hole at the insulator stalk so as to allow an adjustment at right angles to the slot, enabling the conductor-rails to be properly centred in the conduit

As already mentioned, the insulators do from time to time require cleaning, and in the event of no inspection-box being provided for this purpose, some method, such as that of cleaning by means of a water jet, has to be employed In the event of an insulator getting broken, an occurrence which takes place with great rarity, it is necessary to take up the paving at the point in question, and on removing the short steel plate provided over the insulator the latter becomes accessible

CHAPTER VI

ROADWORK

The usual course adopted in constructing a conduit system is to first of all clear the surface of the track and excavate the trenches for the conduit Small concrete blocks spaced at the correct distances are then placed in position, and the yokes placed upon them, levelled, and bolted up to the slot-rails. When this has been completed, formers, constructed either of wood or metal sheeting in such a way as to allow of their easy removal after the concrete has set, are placed inside the yokes to shape the walls of the conduit, enlarging pieces being put in to provide the extra space required by the insulators. The concrete is then put in, forming the walls of the conduit and the under-bedding of the track When this has set, the formers are removed by loosening them

and sliding them along the conduit; insulators and contact-rails are then fixed in position, and after the track rails, tie-bars, insulator-boxes, if

Fig 1147 —Special Construction over Steel Railway Bridge, Paris

any, have been fixed in position, the track may be finished off in the usual manner

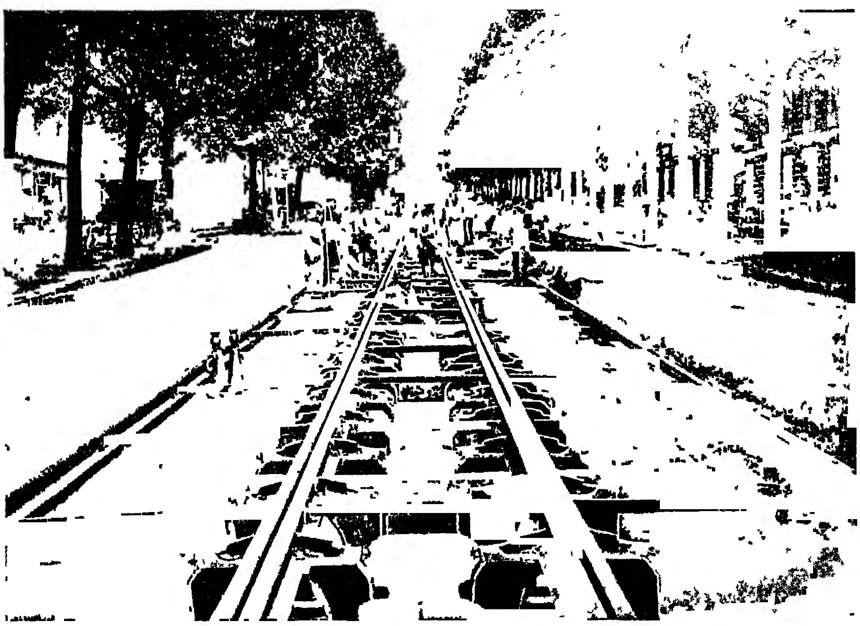


Fig 1148 —Conduit Construction, double track

In the case of side conduits being used, the advantage of construction of having these in the centre of the double track will be realized by inspecting the tracks shown in figs. 1147 and 1148. The former shows

the special shallow iron conduit being put in on the Pont de l'Alma, Paris, the latter, the whole of the railwork being put in together

Fig. 1149 shows plan, horizontal, longitudinal, and vertical sections of the conduit put down by the London County Council

This line was constructed by Messrs. J. G. White & Co., of London and New York, to the designs of Mr A. N. Connett, with some slight modifications suggested by Prof Kennedy.

Full dimensions are given, from which it may be noted that the depth of the conduit is about 24 inches, and the total excavation 2 feet 10 inches from the level of the surface.

The insulator chambers are also shown, the extreme width of the conduit at these points being 2 feet 8 inches, as against $14\frac{1}{2}$ inches normally.

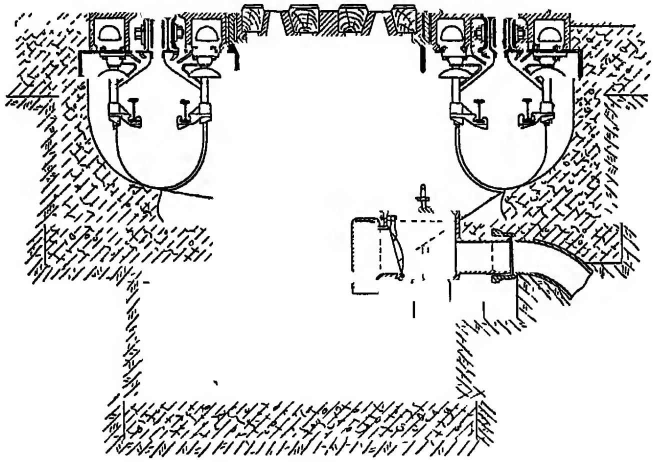


Fig 1150

At the yokes the concrete is 8 inches thick, so as fully to embed them except at the inner surface.

The rate of construction on this contract has been as much as 700 feet per diem

Drainage and Feeders.—The method of construction indicated above is straightforward enough, but it is broken at intervals by the arrangements required for draining. These consist of sump pits, into which the dirt and other debris which falls into the conduit finds its way or is carried into by means of the scrapers. In the first line constructed in New York these pits were very large, being 2 feet 6 inches wide × 4 feet deep, and extended the full width of the track They occurred at every rail joint, *i e* 30 feet apart, the idea being to render the joints in the slot and conductor-rails and the main insulators easily accessible In Brussels they are placed in the centre of the double track, as shown in fig. 1150, and occur at intervals of every 130 feet.

The design of such a pit must be such that it is easily accessible for cleaning out, while the water outlet must be so designed as to carry off rapidly such large quantities of water which might possibly find their way

in in the event of flooding or heavy downpour, while at the same time retaining the solid matter and stopping any gases which may tend to come back from the sewer. The distance apart at which these pits should be placed depends on local conditions, liability to heavy rain, and other considerations.

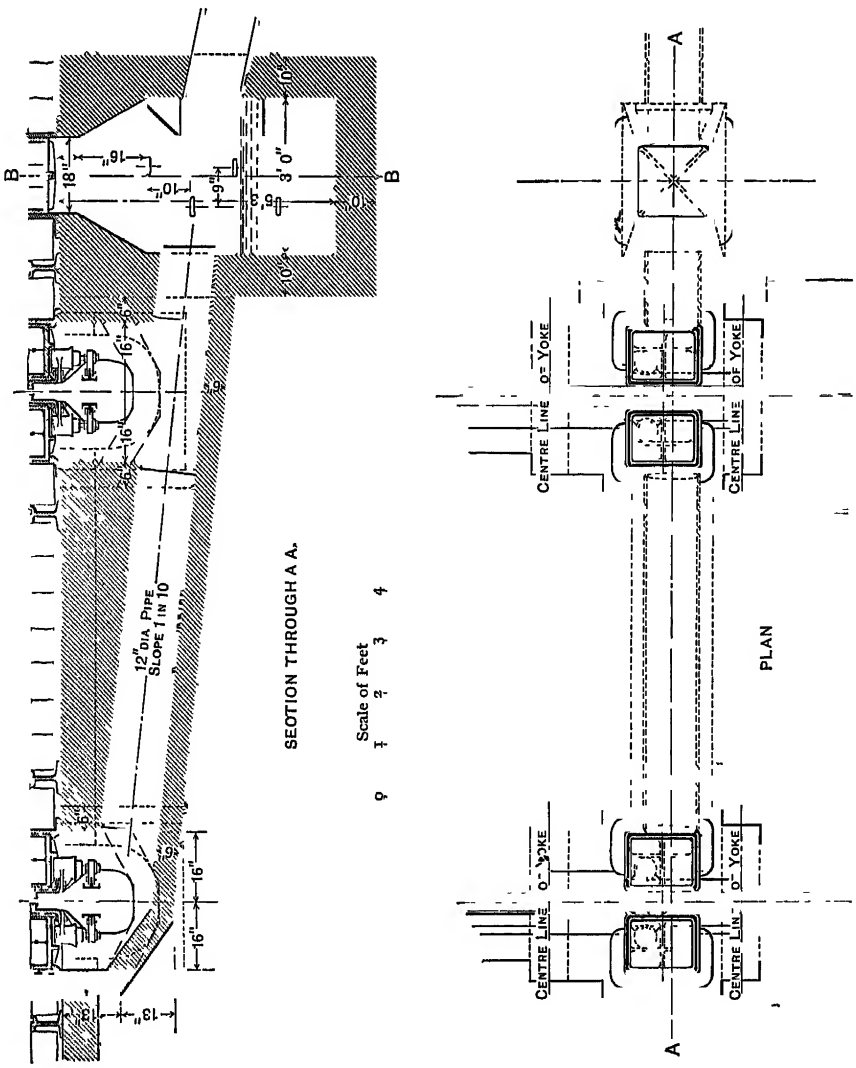


Fig 1151

On the London tramways it has been considered necessary to space them at distances of about 40 yards apart. They are placed entirely outside the track, and are connected to the conduits by means of a 12-inch pipe having a fall of 1 in 10. The chambers are built of concrete, have an internal diameter of 3 feet and a total depth of about 5 feet 10 inches from the surface of the roadway. Over the connection to the sewer a cast-iron hood is placed, as shown in fig 1151, to keep back any

gases which may come through from the sewer, the outlet being placed at such a height as to leave about 2 feet from the bottom of the pit to the water-line This construction may be much more readily cleaned out than the ordinary syphon trap.

In addition to the pits provided for the draining and cleaning of the conduit, manholes are also provided at regular intervals of about every half-mile, and in some other special points, for the connections to the feeder cables. The London lines will be divided up into half-mile sections, at the junction of which section insulators will be placed, and a manhole is provided either alongside the track or in the footpath, as the case may be, from which the cables may be drawn into the feeder ducts and at which the connection to the conductor-rails may be made through the pits in the track. The details of these arrangements may be readily seen in fig 1152, the conductors at these points being interrupted for a length of about 2 feet, the ends of the rails being flared to allow the easy entrance of the plough, and the plough hatches being fixed on these points to allow for the removal of, or for the insertion or withdrawal of, conductor-rails without the necessity of disturbing the slot-rails for this purpose

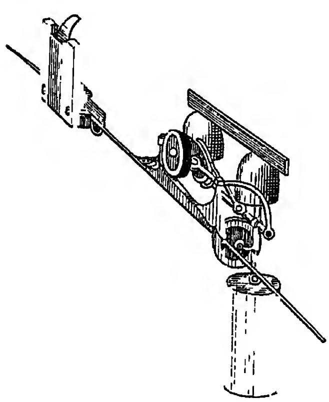


Fig 1153 —Tension Gear

It may be noted here that the use of double conductors necessitates the provision of both positive and negative feeders, or in other words that the amount of cable work is thereby doubled.

In addition to the above hatches, provision is made every quarter-mile for the introduction of conductor-rails, in particular where curves intervene, by means of removable sections of conductor-rail

Such a hatch can also be seen in this drawing

Before finally leaving the question of the conduit design, special attention may be called to the Waller-Manville system, as affording a contrast to the rigid double insulated deep conduit being employed at the present time, in that it utilizes a single insulated conductor, with an earthed return, the conductor being flexible, and also as being the only conduit system essentially differing from the above which it has been seriously attempted to introduce within recent years.

As has already been explained, the great objection made to the employment of flexible conductors is the difficulty of keeping the conductor strained This is effected in the above system by the employment of a special straining device shown in fig 1153

The flexible conductor is supported at the position where this gear is fixed by an arm carrying three pulleys, round which it passes to the tension weight, which keeps the conductor taut

The arm is free to rise and fall with the conductor as the car passes, and as the last pulley carries the conductor through the point of sus-

pension, and the pull of the conductor on one side of the arm is balanced by the corresponding pull on the other, these forces are in equilibrium, and no twist is exerted on the insulators

At curves, arms of similar construction are employed, which hold the conductor in such a way as to leave it free to move. Where such arms are used two insulators are fixed

Further, it is claimed that as, with the exception of curves and some special positions, the conductor is not attached but only rests on the insulators, from which it is lifted by the plough, no strain is thrown on the insulators by the latter in passing, and that therefore a much smaller and lighter insulator can be employed.

Fig 1154 shows a section of the track and conduit between hatchways, from which it will be seen that the running slot-rail is directly carried

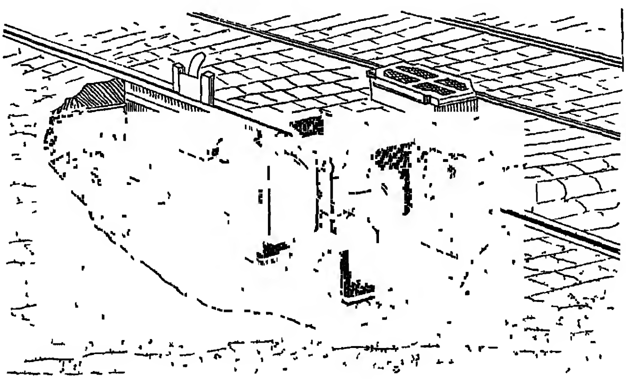


Fig 1154

by the yokes and the wall of conduit, the conductor, being carried under the overhung side, is thus protected from anything entering accidentally the slot Owing to the comparative lightness of the special copper conductor employed, it is not necessary to place the insulators closer than about every 30 feet, *i e* only about half the number are necessary, and they may be conveniently fixed in an inspection-box formed by two yokes placed close together at the rail joints It is also possible to remove and renew the conductor through the slot, and this operation can be performed in a very short space of time The great claim made on behalf of this system is that the actual depth required for the conductor being only that necessary to allow for the sag in the same between insulators, the total depth of conduit required may be considerably reduced, the shape of the conduit being such as to allow of its being very readily kept clean either by hand or by an attachment to a certain number of the cars

The shape and size of the conduit renders the construction of points in the side slot much simpler than when the wider conduit necessitated by the use of double insulated conductors is employed.

By the modification of the details thus introduced, it is claimed that

the lighter yokes can be employed, less excavation is required, and the time and cost of construction very materially reduced.

CHAPTER VII

PLOUGH

We now come to the construction of the plough, which is probably the most difficult problem involved in conduit construction. The details might have been considered at an earlier point, but it is necessary before doing so to gain a clear insight into the various problems involved.

The plough must be so designed that it is of ample strength to resist the various shocks to which it is subjected, and at the same time it must be sufficiently weak, so that, in the event of obstruction, the plough shall break and come away rather than that injury should be caused to the conductor-rails and insulators In addition to this, the plough is that portion of the whole system which is subjected to most wear and tear, while at the same time the proper insulation of its parts is of vital importance to the working of the system, and its dimensions, owing to the space available, have to be reduced to the smallest workable minimum It consists of three portions, the contact-shoes (or "flappers"), the shank, and the suspension gear

Fig 1155 gives the construction adopted on the conduit lines in London The contacts consist of cast-iron shoes which are pressed outwards against the vertical faces of the conductor-bars by means of semi-elliptical springs which maintain a pressure of about 3 lbs The work of moving the contact-shoes along the face of these conductors, however, is not performed by these springs, but is performed by links attached to the shank, as shown in the drawing, which are so arranged as to limit at the same time the outward movement of the shoes This has the advantage that it only necessitates a comparatively small splay in the conductor-bars at points of interruption, and greatly lessens the shock caused when the plough enters at these points. A copper fuse is inserted between the contact-shoe and the conductor in the shank, which would blow in the case of the insulation of the plough breaking down, thereby cutting the faulty plough out of circuit. The shank consists of two steel cutting edges connected by two plates enclosing the conducting leads, and thickened on each side by renewable hard steel wearing pieces, the thickness of the latter being about $\frac{1}{8}$ inch In the boxed space formed by these plates the insulated conductors have to be carried, either of which may be subjected at any time to the full working pressure of the line The thickness of the whole arrangement with a $\frac{3}{4}$-inch slot does not exceed about $\frac{1}{2}$ inch, as with the most careful setting the slot has been found under some circumstances to close to $\frac{5}{8}$ inch.

The insulation of the two conductors in the plough is one of the weakest points in a conduit system, and probably gives rise to more

break-downs than any other cause. As a rule no difficulty arises in dry weather, but incipient faults begin to develop directly wet weather sets in In Paris the plan is adopted of providing a double equipment of ploughs, *i e* a duplicate set is kept in depot, and after a wet day the ploughs on the whole of the cars that have been out are changed, those

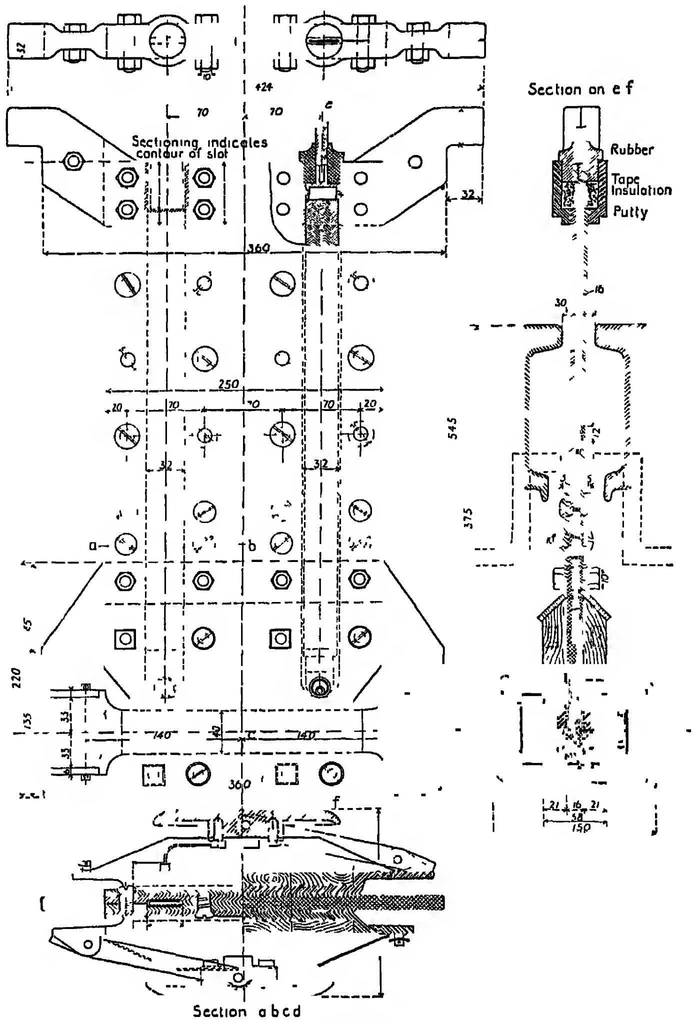


Fig 1155

taken off being thoroughly dried out and well soaked in insulating compound. This plan has proved thoroughly successful, and break-downs from this cause have been reduced to a negligible quantity

Another method of constructing the shank is to make the cutting edges slightly thicker than the box portion in the centre. They then not only carry all the strains, but are subject to all the wear, and must in conse-

quence be easily replaceable. As these cutting edges must form the main groundwork of the shank, the first construction is probably much the simpler to maintain as regards wear, while in the second the insulated conductors may be more readily accessible The Simplex plough was constructed in this way, and is shown in fig 1156. There being only one conductor the contact is on one side only, and forms a bed on which the flexible conductor rests The centre portion is easily renewable

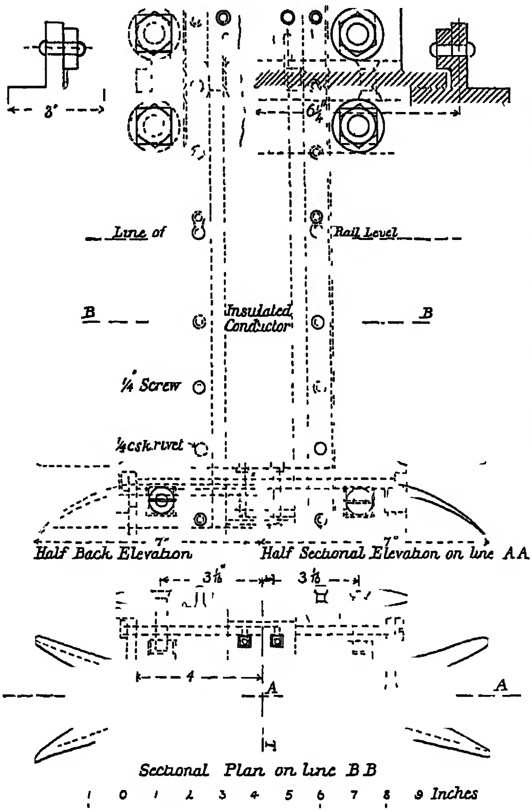


Fig 1156 —Details of Collector—"Simplex Conduit"

The plough in use on the lines in Paris is very similar to that shown for the London lines, differing only in slight details, hatchways being used for inserting the plough into the conduit

In the ploughs used in Berlin and Brussels the contacts are hinged on a horizontal axis parallel to the slot, the flappers being pressed by springs into a horizontal position They are forced into the vertical whenever the plough passes through the slot, in which position they lie flush with the shank

The pressure between the flappers and the conductors is about 3½ lbs

The flappers are in themselves mechanically weak, and the shocks produced both to the plough and the conductor-bars are much greater than with ploughs where the contact-shoes are pressed by means of semielliptical springs, and whose range of movement is limited, and further, this type of construction does not allow of fixing a fuse between the flapper and the conductor in the plough shank, with the result that should the insulation of the latter break down the whole section is put to earth, blowing the section cut-out, the fault only being got rid of by the finding and removal of the faulty plough Of course where this can be done through the slot it is not so serious as it would otherwise be.

In the London and Paris ploughs a much better contact is obtained, the area being probably 10 to 15 square inches, and is practically unaffected by small vertical movements.

As these ploughs cannot be removed at any point through the slot,

the shanks have to be sufficiently strongly held to be able to clear the slot of any ordinary obstruction.

In the old Blackpool conduit the ploughs were attached to the cars by means of leather straps If an unusual obstruction was encountered the strap broke and left the plough in the roadway.

Suspension Gear.—Where the cars will only have to run on a conduit track, and it will not be necessary to raise the plough out of the conduit, the suspension gear is comparatively simple. For reasons already explained it is very desirable that the plough should have a free movement across the full width of the car, and slides should be provided for this purpose, but they should be so constructed that while allowing the plough freedom to turn slightly to follow freely the course of the slot, they must at the same time prevent any tilting due to any slight obstruction met with in its progress.

In Brussels, where the side conduit is used, provision is only made for lifting the plough out of the conduit, the driving arrangement being designed with a certain amount of lateral play so as to allow the necessary freedom for taking curves, &c As the conduits are constructed on the inside of the track, and on the return journey the conduit will be on the other side of the car, it becomes necessary at the end of the journey to provide conduits under each track rail, the cars being fitted with two sets of ploughs

Where, however, a mixed system is employed, the construction becomes complicated with the gear necessary for raising the plough out of the conduit, and becomes practically part of same

Mixed Systems.—Owing to the cost involved in its construction, the conduit system will never be employed for the outlying portions of a tramway's net-work, and it follows therefore that while its employment in the central portions may be justifiable, unless a special set of cars are to be put aside for the working of the section so constructed it will be necessary to so arrange the car equipment as to be able to work on the overhead or some other systems as well as the conduit.

This involves either (1) the disconnection of the plough from the car, or (2) its removal from the conduit, *i e* either the plough shall be carried continually on the car, being raised up when not in use, or removed and replaced on the car at each junction of the two systems

The latter would appear to be the simpler method, a manhole of convenient size being provided under the track, arranged so as a man can carry out the necessary operation each time the car arrives at these points Very little consideration, however, will show that this arrangement is undesirable and rather expensive It has, however, been successfully used at Washington, the point in question being a natural stopping-place for traffic purposes, and the plough is removed without lengthening the stop made by the car It is quite true that in some such positions, where points at the same time occur and where there is a very heavy traffic, that it will be necessary to keep an extra man in attendance, but, even under these circumstances, he is likely to be of more use above-ground

An arrangement, therefore, which retains the plough on the car is one

which is more to be recommended The simplest and neatest solution is to raise the plough out of the conduit through the slot without any special alteration to the slot This has been successfully done both in Brussels and Berlin, the plough being so designed as to allow of its removal from the ordinary width of slot in use at those places

Plough-raising Gear.—At Berlin, in fact, the arrangement is almost automatic. A wheel is fixed to the under side of the plough, and an inclined plane being constructed at the end of the conduit section, when the car reaches this point the wheel comes in contact with this plane and forces the plough gradually out of the slot, when it is raised clear of the track by turning a crank. All that is necessary, therefore, is for the conductor at the same time to release the trolley pole and bring the wheel

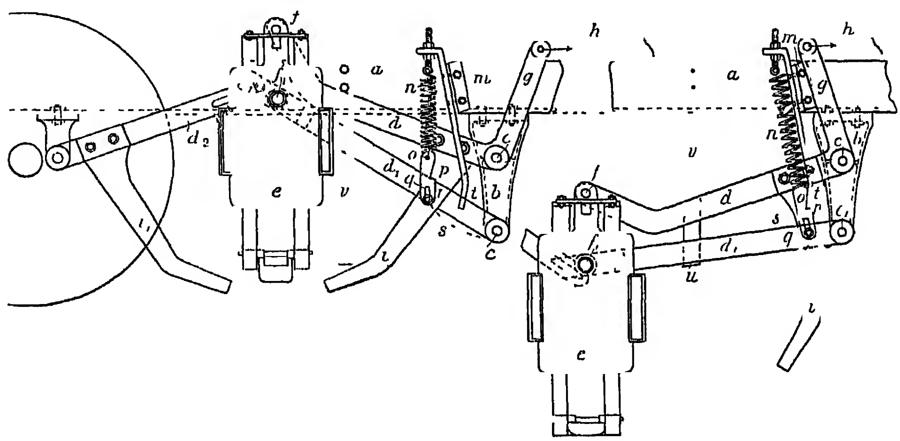


Fig 1157 —Plough raising Gear, Berlin

on to the overhead conductor In Brussels the arrangement is slightly different, the plough being always raised by hand through the slot by the motor-man

A second arrangement also in use at Berlin is shown in fig 1157.

The plough is so constructed that it is automatically lifted out of the conduit in the event of the slot being obstructed by any foreign substance The bracket *b* (fig 1157) is bolted on to the longitudinal frame of the car. On this bracket the two levers *d* and d_1 are pivoted by the bolts *c* and c_1. The contact-plough *e* is suspended on these levers by the bolts *f* and f_1 in such a way that the plough is free to turn on the bolts, and that the lines between these bolts or pivots, $f f_1$, $c c_1$, form a parallelogram This ensures that the plough is always held in a vertical position. The lever arms *d* and *g* are in one piece, and to the end of *g* is attached the rod *h*, which extends to the platform of the car. This bar is used by the conductor to lift the plough out of the slot when required. The lever *d* also carries the small link *o*, to which the spring *n* is attached. The notch *p* in this link engages, when the plough is down, with the stop *t*. This stop is bolted to the car frame at *m* The path of motion of the pivot *r* is shown in the drawing. Thus the plough cannot be lifted by the spring

while the stop is engaged in the notch p As the car moves, however, if the lever i, which is in the slot, meets with an obstacle, the lever d begins to revolve round c. In this way, after a small movement, the catch is released, and the spring then raises the plough completely out of the slot. A second lever i_1 d_2, on the other side of the plough, gives the release in a similar way if the car is travelling in the opposite direction The above arrangement tends not only to lift the plough when an obstacle is met, but the levers i and i_1 also prevent the plough itself from receiving the shocks caused by meeting such obstacles.

Both these constructions, however, require the plough to be constructed in a special manner, the contact being made with conductor-rails by means of "flappers", making contact either on the top or side of the conductor-rails, against which they are pressed by springs. This method of plough construction has, however, the following disadvantages —

The ploughs have to be specially weighted in order to carry them down into the conduit and to maintain the proper pressure with the conductor-rails against the forces exerted by the flapper-springs, while in the case of horizontal flappers the contact between the flapper and the contact-rail is much inferior, owing to the variation in the contact area by slight vertical movement in the plough

Although this arrangement of removing the plough through the slot is very simple, and has worked quite successfully in the towns in question, it is only feasible with a slot of at least $1\frac{1}{4}$ inch in width, and is quite out of the question with the employment of a $\frac{3}{4}$-inch slot allowed in this country.

With side-slots, however, which are in use at these towns, owing to the natural width of the groove in the rail, the extra slot width is not so noticeable

Where it is not possible to raise the plough through the slot, plough-hatches similar to that shown in fig 1155 have to be used

A mark is made on the track showing the driver the exact position in which to stop his car. The driver raises the plough out of the slot, while the conductor opens the trap and places the trolley-pole in position

In Paris, where both side and centre conduits are in use, slides are provided to enable the plough to move the full width of the car frame, and at the same time hoisting gear is provided for raising the plough out of the slot in the central position

By the courtesy of the Institute of Mechanical Engineers and Mr. A. N Connett, the author is enabled to include the following description of this device —

"Fig. 1158 gives three views of the apparatus. A are the side bars, B the top bar of the truck, and C the brake rods, which must be placed outside the wheels as here shown. D is the plough, shown in position on the side-slot conduit; it slides from this position to that of (1) for the centre-slot, or of (2) for the side-slot of the other track when crossing from the inner conduit on one track to the inner conduit on the other track. The bars E are the slideways. The bars F prevent the plough from rising or tilting in the conduit, except in the central posi-

tion (1), where the casting G, held in position by the lock H, performs the same function. The slide-bars E and F are held in position by the steel castings I. The projecting central piece J, braced as shown, holds the plough in its raised position. The whole apparatus is supported by the channel beams K, which are bolted to the side bars of the truck. In this way the vertical variation in height is limited to the small movement in the axle-box springs of the truck. The plough is raised in the following manner:—The fixed screw L is turned by means of a removable crank placed at M. The block N travels from one end of the screw

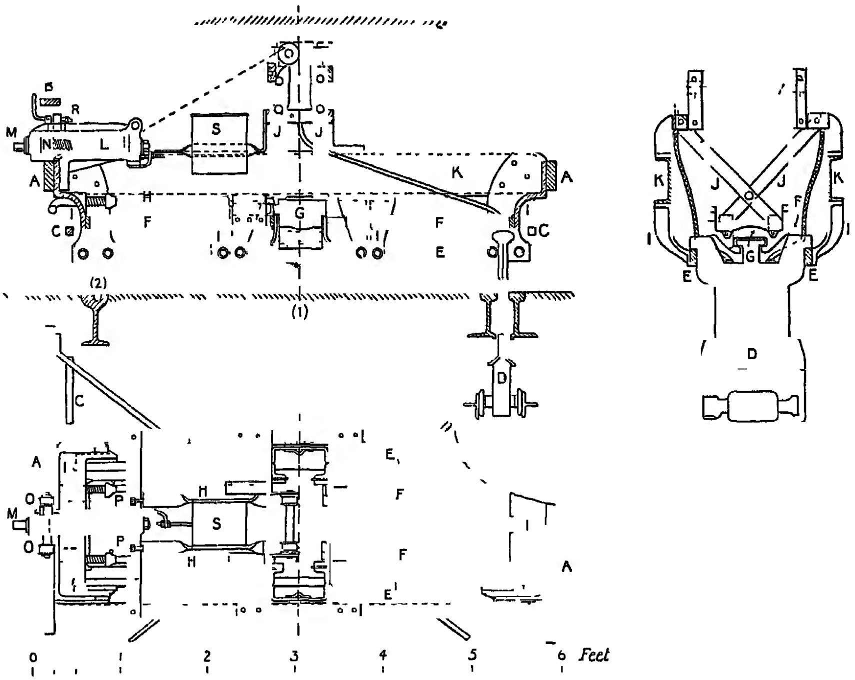


Fig 1158 —Plough, with Raising and Lowering Device, Paris

to the other, it is shown in its position when the plough is raised, it carries the two rollers O, over which run heavy-link chains The latter are fixed stationary at one end P, and at the other end are attached to the casting G, which is thus raised by an amount equal to twice the travel of the block N. The latch R automatically locks the block in place when it reaches the outer end of its travel. This prevents the shaking of the truck from lowering the plough when it is in its raised position for the overhead-trolley section of the road The box S covers the double-pole switch, which puts the car-leads in circuit either with the overhead or with the conduit line. This is done automatically with the raising or lowering of the plough by means of a rod, which is moved by the block N when near the end of its travel in each direction. Figs. 1159 and 1160 are side views of the truck alone so equipped, and fig. 1161 is an end view of the same truck. The author is indebted to

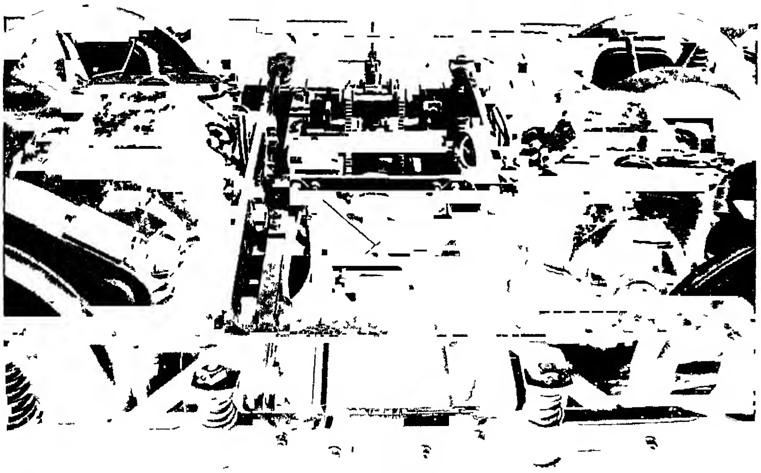


Fig 1159

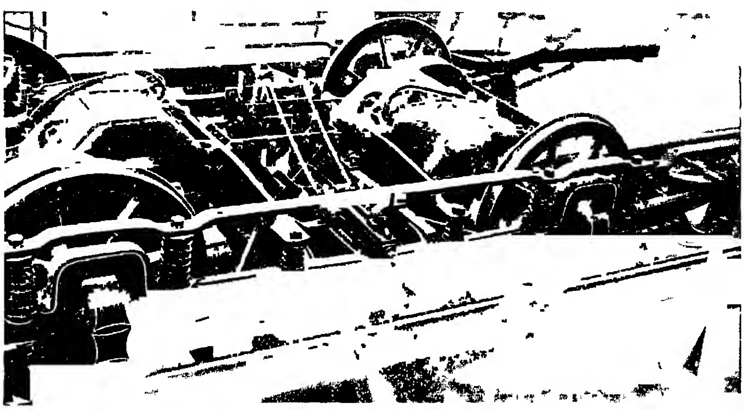


Fig 1160

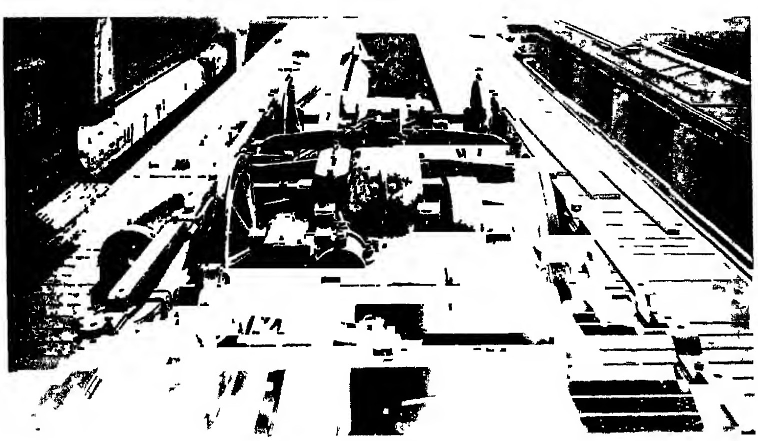


Fig 1161

To face iv, 196

SIDE VIEWS AND END VIEW OF TRUCK OF CAR EQUIPPED WITH PLOUGH APPARATUS

Mr. E. W. Mix, the chief engineer of the Société des Établissements Postel-Vinay of Paris, for his invaluable assistance in the design and manufacture of the apparatus above described That it has been successful is largely due to his efforts."[1]

Not the least interesting point in connection with this equipment is the arrangement by which the winding of the plough out of the slot automatically operates the switch-gear for disconnecting the plough and putting the trolley into circuit

By shaping the piece M, fig 1158, in such a way as to fit only such a controller handle as can be removed from the controller in the "off" position only, the employment of the handle of the controller ensures that no movement of the latter can be made during the operation of raising the plough The arrangement shown in these drawings could, of course, without great difficulty, be modified so as to raise the plough in other than central positions

Earth Returns with Mixed Systems.—In connection with the subject of mixed systems it might be mentioned here that the usual practice, owing to the one side of the trolley system being earthed, is to employ for the conduit sections *entirely separate circuits and generating plant, with separate feeders* from the generating or sub-stations

Unless this is done it means that the negative pole of the conduit line is earthed by the trolley sections, and it is not possible to ascertain, therefore, the insulation of the negative conductor-bar

In the author's opinion, however, no special disadvantage would occur even if the negative pole were earthed at the generating or sub-stations, as, owing to the drop in the conductor-bars, the greater portion of the negative bar would be slightly *above* earth potential, tending to improve the insulation.

Judging by the tests given on p 166, the negative conductor-bar is generally (roughly about 10 to 15 volts) *below* earth potential

The earthing of the negative pole would therefore obviate the necessity of running separate generating plant, or the putting down of sub-stations specially for the conduit sections, even if it were still necessary to retain separate feeders and switch-gear

If the only final argument in favour of a double insulated system is that the negative conductor forms a reserve to the positive, then it would be better to have two positive conductors used in parallel, entirely disconnected from each other, except at the feeding points, through cut-outs.

Were a thoroughly reliable unipolar conduit system to be designed, the same machines might be run on both sections, while the complicated arrangement of the switch-board, with the throw-over switches, feeder reversing switches, earth indicators, &c., would all be avoided with the negative pole put to earth

[1] Extract from paper by Mr. A N Connett.

CHAPTER VIII

COST OF CONDUIT TRAMWAYS

In dealing with this aspect of the question it is only possible to do so in a very general way. For the purposes of comparison three examples are given, showing the cost of putting down conduits per mile of single track in Washington, New York, and London respectively. (See Appendix.) The cost to the London County Council for the first section put down by that body amounted to about £13,500 per mile of single track, inclusive of a sum of about £1000 per mile provided for shifting gas and water mains and other obstructions met with in the construction of the conduit. In comparing this with the estimates of the American lines it must be borne in mind that the cost of the metallic work in the New York and Washington figures is less than the amount for which the same items could be purchased to-day.

In considering the question of the cost of construction of a conduit system a number of items, including costs of excavation, carting, concrete, and paving, as also the question of temporary tracks, special work, drainage, and underground obstructions, must necessarily depend to a very large extent on local circumstances. The cost of constructing a side-slot conduit would be, according to Mr. A. N. Connett, about £500 per mile of single track less than that of a centre-slot. It is also evident that the side-slot gives some advantage as regards special work by reducing the number of frogs, points, crossings, &c., there being only two sets of rails instead of three, the number of special pieces with centre-slot being in some cases doubled, or even trebled. This advantage, however, is lost if the proposed suggestion of bringing the slot into the centre of the track at points, &c., is adopted, as in that case the number of pieces would be still further increased by the extra slot turn-outs. The item of special work is in large conduits one of exceptional difficulty, as until work is fairly started it is in many cases impossible to obtain any definite knowledge as to the items to be provided for under this head. Many difficulties apparently serious may be occasionally avoided, *e.g.* cases in which it has been possible to avoid alterations to heavy water mains by the simple expedient of raising the surface of the roadway a few inches. In some cases where roads cross very shallow railway bridges it may be necessary, even after reducing the conduit depth to an absolute minimum, to build special bridge-work in order to overcome the difficulty, and there is no doubt that the expenses of work of this nature may bring the very high cost of conduit construction to an almost prohibitive figure.

In comparing the cost of conduit construction with that of other forms of electric traction, in particular the overhead-trolley system, it is not always easy to draw an absolutely fair comparison, owing to the fact that the cost of double track with overhead lines is nothing like double the cost of single lines. As, however, the number of cases

where single-track system is likely to be employed are very scarce, the comparison can best be made on the basis of double track.

The cost of double-track overhead equipment may be put at from £1200 to £1800 per mile of double track, according to local conditions and the type of construction adopted, but as installed in most of our large towns will probably not be less than £1600 per mile The cost of the permanent way complete, including foundations, track rails, paving, &c, under the same conditions, may fairly be taken at £11,000 per mile of double track, *i e.* a total of £12,600 per mile of double track

Taking the cost of the conduit system as, roundly, £27,000 per mile of double track, it would accordingly work out at somewhat more than double that of the trolley system, or, say, an increased cost of £15,000 per mile of double track (including extra cost of feeders, car equipments, and other items).

This extra expenditure would involve, for the purposes of interest and sinking fund alone, an extra sum of £900 per annum per mile of double track, in addition to which must be added the extra cost of maintenance and cleaning incurred with the adoption of this system According to such figures as are obtainable it would appear that the cost of cleaning would add an item of something like 0 06*d* per car mile to the working expenses, while the cost of maintenance would appear to be about 0 3*d* per car mile in favour of the overhead system. Assuming, therefore, on the basis of an average two-and-a-half-minutes schedule throughout the day of sixteen hours, there would be, per mile of double track, a car mileage of about 280,320 car miles per annum In order to cover the increased annual charge given above it would be necessary, therefore, to take receipts amounting to

$$£900 \div 280320 \times 240 = 0\,773d \text{ per car mile,}$$

to which must be added the difference of 0 360*d* per car mile, making a total of 1.133*d* per car mile over and above that required for the operation of the same lines by trolley system. If the car frequency were double that given above, this figure would, of course, be reduced to 0 746*d* per car mile

As the average takings per car mile with electric traction in our large towns in this country only in exceptional cases exceed 15*d* per car mile, it is obvious that it is only to the very central portions of such net-works that the conduit system can be applied without considerably reducing the margin between receipts and expenditure

It is also clear that there is an opening for inventive genius to devise a system for large towns which shall give equal security to life and efficiency in working at a less cost of maintenance and very considerably reduced capital outlay, without increasing the already too numerous street obstructions

In conclusion, the author wishes to tender his thanks to Mr A. N Connett, Mr. J. H. Rider, Mr. Philip Dawson, the Institute of Mechanical Engineers, *The Tramway and Railway World*, and others, for their kindness in supplying information and other assistance

APPENDIX

COST OF CONDUIT SYSTEMS IN WASHINGTON—NEW YORK—ENGLAND

The author is indebted for the following particulars to Mr. A. N Connett, who has been directly responsible for the lines in Washington and London:—

Details of Cost in United States—The following table gives the actual cost per single-track mile of the conduit roads constructed for the Metropolitan Railway of Washington, D C.

COST OF METROPOLITAN RAILWAY, WASHINGTON, D C (1895–96)

Straight track ...	101,660 feet
Curved track ...	9,190 „
	110,850 feet—say, 21 miles of single track

Rails and splice bars per ton—

	£	s	d.	
Wheel-rail	5	15	0	per ton
Slot-rail	6	8	6	„
Guard-rail for curves . ..	9	10	0	„
Conductor-rail	8	8	0	„
Joints complete .	0	4	10	each

PER MILE OF SINGLE TRACK

	£	s	d
Rails and splice-bars	1858	6	8
Cast-iron (yokes, insulator frames, covers, &c), 215 5 tons at £5, 15*s*. 7*d*. .	1245	8	2½
Bolts, tie-bars, clips, &c.	312	10	0
Bonds for conductor-rails	97	18	4
Track laying—hauling and all labour	589	3	4
Temporary track .	33	6	8
Excavation of all kinds except for cable ducts, 2507 cubic yards at 3*s* 10¾*d*.	488	6	10
Sewer pipes laid, and brickwork for duct manholes	99	7	6
Cable ducts— 10,616 feet 12-way duct at 4*s*. 9½*d*; 41 „ 8 „ „ 3*s* 6½*d*.; 21,354 „ 4 „ „ 2*s* 2¼*d*; 113 „ 2 „ „ 1*s*. 5*d*. } £4894, 3*s*. 9*d*. ...	233	1	1
Excavation for cable ducts, 9207 cubic yards at 3*s*. 4*d*. = £1534, 10*s*.	73	1	5½
Concrete, first grade, for conduit (1 barrel Portland cement to 12 cubic feet sand and 22½ cubic feet broken stone), 765 cubic yards per mile at £1, 9*s*. 2*d*.	1115	12	6

	£	s.	d.	£	s.	d.
(Cumberland cement to 10 cubic feet sand and 20 cubic feet broken stone), 514 cubic yards per mile at 18*s* 1*d*.				464	14	10
Stone paving, using old setts—						
42,126 square yards at 3*s* 3*d*.	6845	9	6			
Asphalt pavement—						
91,716 square yards at 6*s* 0½*d* .. .	27,705	17	6			
	34,551	7	0	1645	6	0
Special track work and curves .				783	6	8
Extra bills of street contractor .				239	11	8
Removal of sub-surface obstructions .				666	13	4
Total cost per mile of single track ..				9945	15	1

The metallic structure cost less at that date than it would now. The temporary track is a low item, because the authorities permitted a flat strap-rail to be laid on the pavement (mostly asphalt) by means of flat tie-bars with special seats at their extremities It should be stated that Washington is an exceptionally favourable city for the construction of conduit roads, because the streets are wide and with little traffic upon them, and the supervision is by the thoroughly trained engineers of the United States Army

A pamphlet, containing some diary notes kept by Mr William C. Gotshall, engineer in charge of construction of the Second Avenue Railroad of New York, concludes with the following estimate of the cost of this road per mile of single track The estimate is not Mr Gotshall's, but is the work of the compiler of the pamphlet —

TOTAL COST PER MILE OF SINGLE-TRACK OPEN CONDUIT, SECOND AVENUE RAILROAD, COMPILED FROM DIARY OF W C GOTSHALL

	£	s.	d.
Labour, digging trough, removing old track, repairing concrete, removing excess dirt, hauling all track work, £1, 10*s* 11½*d*. per linear foot	8173	0	0
Insulators, 5*s* 8*d* each .	199	9	7
Iron work, excluding yokes, 7*s*. 4*d* per linear foot ..	1375	7	0
Cost of cast-iron yokes, 224 7 tons at £5, 4*s*. ...	1168	8	10
Concrete, ⅜ cubic yard per linear foot, 8*s*. 2*d*. per yard ...	808	10	0
Haulage on yokes and iron work . ..	117	1	8
Total, exclusive of paving and feeder duct .	11,841	17	1

In comparing this cost with that of the Washington conduit, it should be borne in mind that the items of cost for special track work, feeder ducts, paving, bonds, sewer connections, and temporary track are not included in this estimate, while they are in the Washington costs The cost of concrete is here put down at 8*s* 2*d*. per cubic yard, which is evidently an error of compilation; other information in the pamphlet seems to prove that it should be from 2½ to 3 times this amount.

7th August, 1902

ESTIMATE COST IN ENGLAND OF CENTRE-SLOT CONDUIT TRAMWAY

Per Mile Single Track

	£	s	d
Wheel-rails (90 lbs per yard), 141 tons at £7	987	0	0
Joints, 8 tons at £8 . . .	64	0	0
Slot-rails (66 lbs. per yard), 105 tons at £8 .	840	0	0
Conductor-rails (22 lbs. per yard), 34 6 tons at £8 ..	276	16	0
Haulage, 288 6 tons at 3*s* ..	43	6	0
Bolts, washers, &c., 4 tons at £18	72	0	0
Tie-bars, 13.5 tons at £30 . .	405	0	0
Insulators (complete), 710 tons at 5*s*. 3*d* . . .	186	7	6
Cast-iron yokes and insulator pit covers—			
Yokes, 160 lbs each (3 ft 9 ins centre), 101 tons at £8, 15*s* Covers, 120 lbs each, 38 tons at £8, 15*s* } ..	1216	5	0
Haulage, 139 tons at 3*s*	20	17	0
Bonds, 310 pairs at 4*s* 6*d* .	69	15	0
Concrete for tube, 950 cubic yards at £1, 3*s*	1092	10	0
Concrete for paving base, 600 cubic yards at 17*s*	510	0	0
Excavation tube, 630 cubic yards at 5*s* ..	157	10	0
Plate-laying, 1760 yards at 6*s*	528	0	0
Sewer connections, 15 at £15 (half cost of D T con)	225	0	0
Excavation and haulage (old paving and track), 4700 square yards at 3*s* 2*d*	744	3	4
	7438	9	10
Waste—Extras and contingencies 5 per cent	371	18	6
	7810	8	4
To which must be added—			
Paving . . .	3100	0	0
Obstructions .	1000	0	0
Proportion of special work	1100	0	0
Temporary track	500	0	0
Total	13,510	8	4

7. Rolling-Stock and Equipments

CHAPTER I

TRAMWAY CAR BODIES

In writing on the subject of rolling-stock and equipments we have no intention of reviewing the gradual development of this branch of the engineering profession from its inception We were till recently to a great extent indebted to the energy and perseverance of those in America, and in a lesser degree to Continental enterprise, for our knowledge and experience in this direction

With the introduction of electric tramways so generally into Great Britain, it was not long before new factories for the production of both cars and equipments were running, and existing factories were remodelled on more modern lines for meeting the increasing demand for tramway rolling-stock Speaking generally, these factories are operated upon lines as nearly approaching the American practice as circumstances in this country will allow

The conditions of our tramway service vary widely from those in America, and it is not therefore surprising that the most popular types of American cars are but little seen in Great Britain—we refer to the single-deck open cross-bench single-truck, or bogie car, and the single-deck closed single-truck, or bogie car

The travelling public here are not satisfied unless they can ride on the top of a car, and this preference is no doubt due more than anything else to the fact that the old horse-cars were nearly all of this design In passing, it may not be out of place to mention here that the double-deck car is almost unknown in the United States of America It is quite obvious that in climates where great heat and cold are experienced this class of car would be of little use, owing to the unprotected state of the top deck, but the almost universal adoption here of the double-deck car for electric tramways does not entirely depend on the favour in which it is held by the public, but depends also to a very large extent on its all-round economy, its low working expenses, passenger accommodation, and the small amount of shed-room required to store it.

Very radical departures in design from horse-car practice had to be made to render these cars suitable for electric traction. The underframing more particularly had to be strengthened to meet the severer conditions of a self-propelled vehicle, with higher speeds and more rapid acceleration.

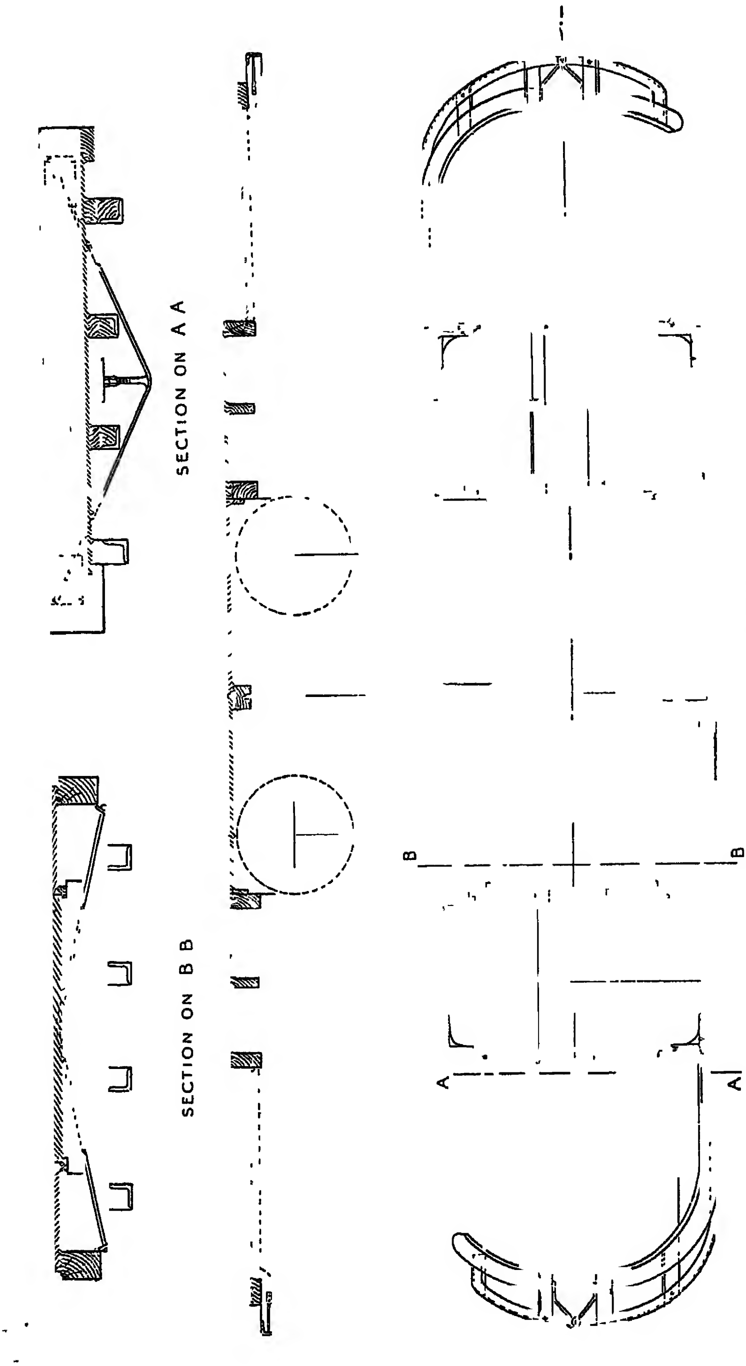


Fig 1163.—Under-Frame of "Bellamy" Reversed-Staircase Car

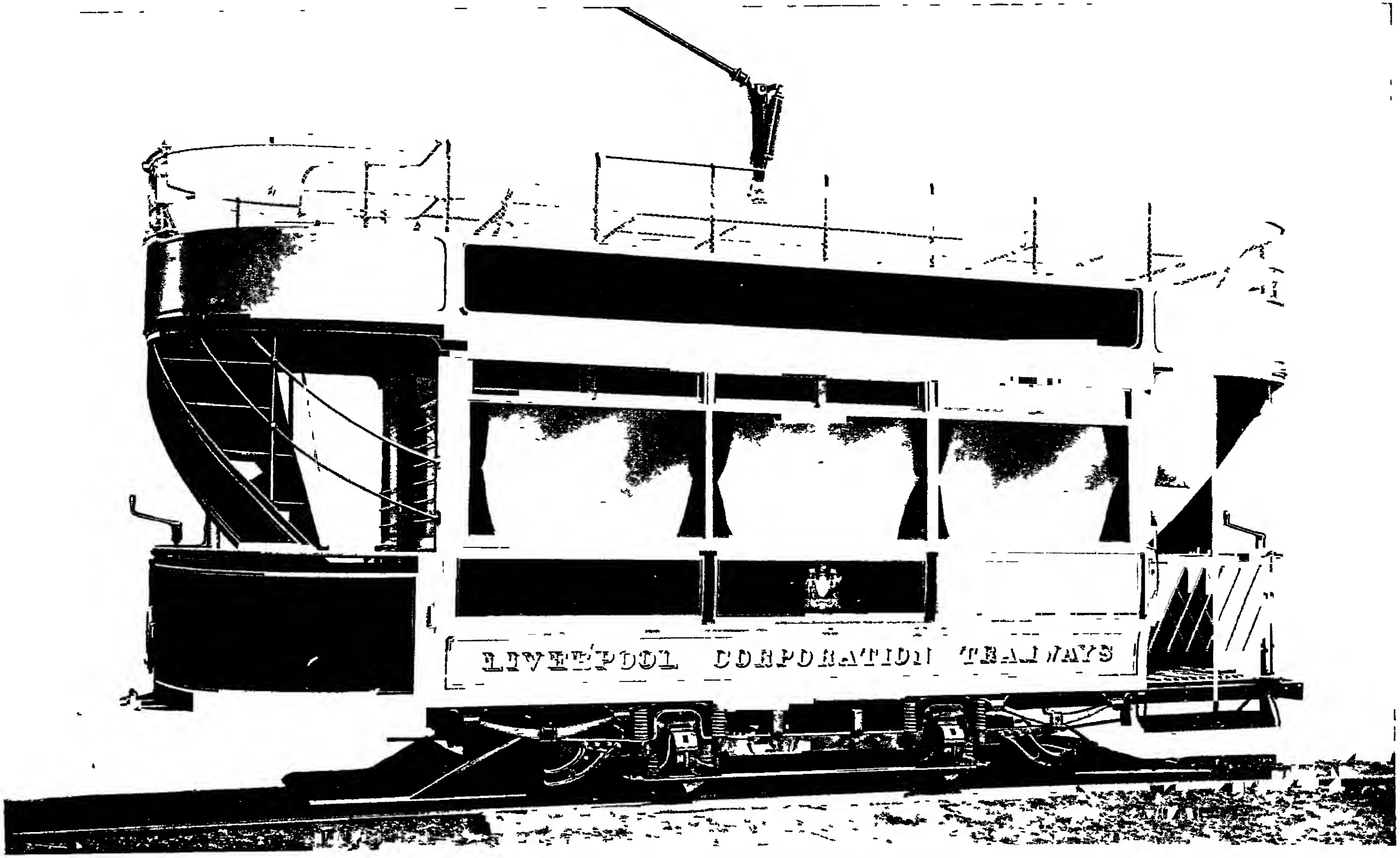


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Fig 1162 —BELLAMY REVERSED STAIRCASE CAR

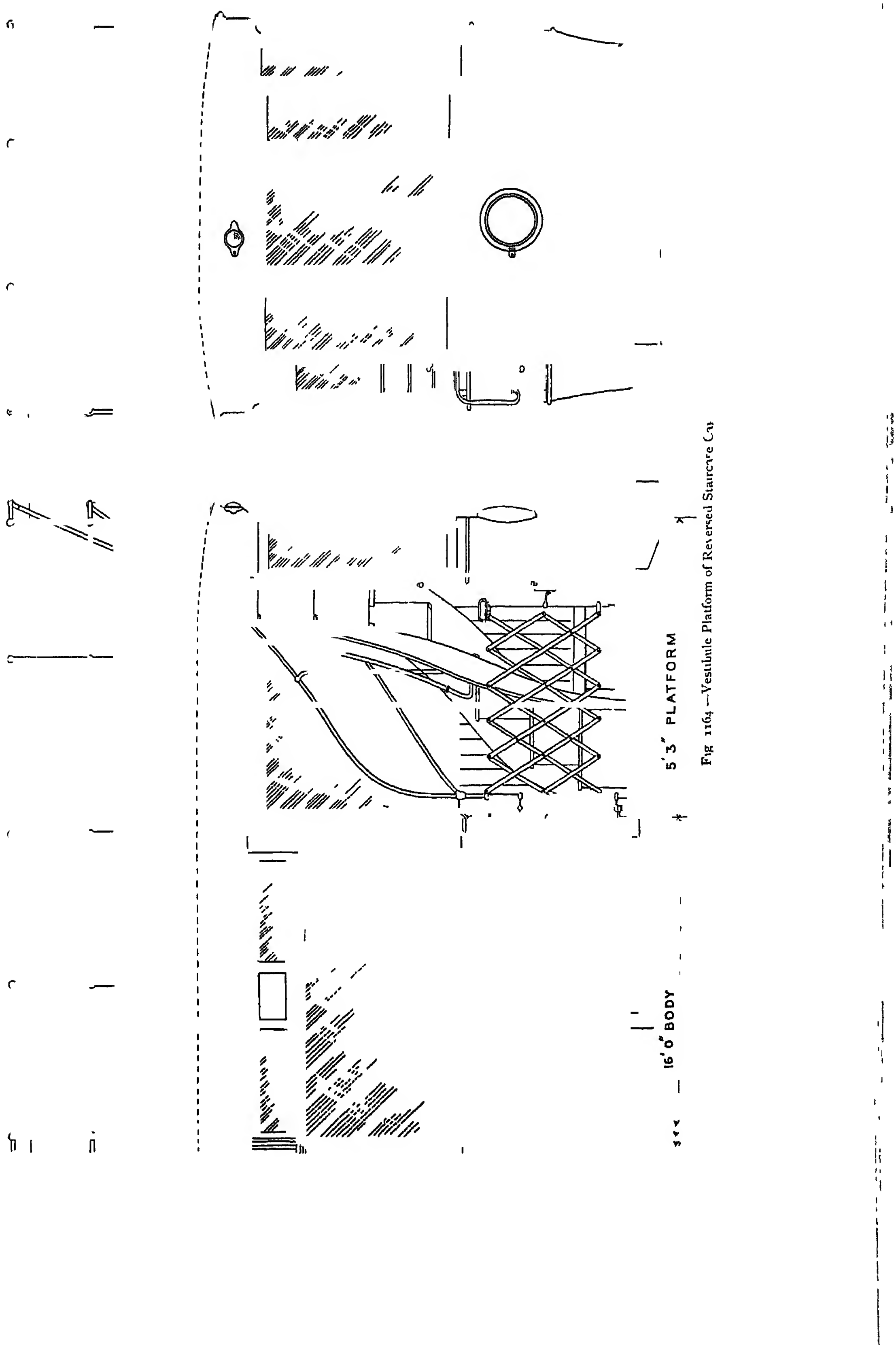

Fig 1164.—Vestibule Platform of Reversed Staircase Car

Accommodation also had to be provided for the car-truck to which the motors are attached

The double-deck car recommends itself as affording seating accommodation both under cover and in the open, and having with a given over-all dimension the greatest seating capacity obtainable Certainly the most popular type of double-deck car is that known as the "Bellamy" reversed-staircase car, the general arrangement being shown in fig. 1162, the underframing of which is depicted in fig 1163.

Besides the increased safety to passengers negotiating the stairs on this type of car, the arrangement renders it possible to seat a greater number of passengers without increasing the length of car. The reversed stairway offers greater shelter both to the motorman and conductor, and a very slight addition is required to vestibule the ends of the car, thus completely enclosing the platforms

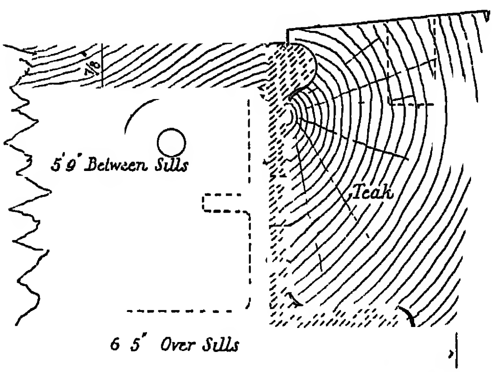

Fig 1165—Combination of Bulb Steel Section and Teak for Car Side-Sills

So far, vestibule cars are not very popular in this country, chiefly on account of our winter seasons not being sufficiently severe to make them a necessity. A vestibule has several disadvantageous features, namely increase of weight, and difficulty in seeing in snowy weather, or when the windows get steamy from the heat inside, and in beating rain It is difficult also to see at night, unless the car lights are carefully shaded from the driving platform, owing to reflection from the vestibule windows Fig 1164 shows a modern vestibule platform on a double-deck reversed-staircase car.

The main underframing of the cars should be preferably of teak or oak. In the case of long bogie cars it is generally advisable to reinforce the timber of the side-sills with steel section, and for this purpose bulb section, as shown in fig. 1165, is preferable to a channel section, as it allows the mortising of the side-sills for the corner and side pillars to be carried out in the usual manner, All mortised joints should first be covered with white-lead, and brought together at a driving fit.

The selection and seasoning of the timber is a most important operation, upon which depends to a great extent the life of the car.

Selection of Timber.—The various kinds of timber suitable for car construction are offered to builders in the general market in two forms, namely, in the log and in the plank, and different builders make their selection from either or both as circumstances require.

Selection from log stock to be cut into planks for car work requires the greatest skill, and none but those who have had large experience in this particular direction succeed in securing satisfactory results. The main advantages of selection from this form are: the long lengths, wide widths,

and minimum first cost that can be secured. Its disadvantages are: the large amount of waste when converting such logs into planks, and the long time required for seasoning before it can be used in car-work.

Selection from plank stock direct offers a much safer and more satisfactory method in the long run. Its advantages are an open inspection of each plank, a minimum amount of waste in cutting to the various sizes required in the work, and an advanced stage of seasoning Its disadvantages are: the difficulty of securing long lengths and wide widths, but as advanced orders can be placed to cover these disadvantages, selection from plank stock is considered the most satisfactory

The kinds of timber most used in car construction are as follows:—

Main Framing.	Outside Finishing	Inside Finishing
Teak	Teak	Teak
Oak	Mahogany	Mahogany
Pitch Pine	Canary Whitewood	Quartered Oak
Ash		Ash

Teak.—The value of teak as an all-round timber is well known and much appreciated, especially in England, where large quantities are used in all departments of railway work For this reason it is placed at the head of the above list, for main framing and for both outside and inside finishing Its average weight in its seasoned state is 46 lbs per cubic foot, and its tensile strength 12,000 lbs. per square inch; its transverse strength 2500 lbs per square inch Its chief value as a framing timber, and for outside finishing, arises from its oily nature, which preserves it from rot under varying conditions of moisture to which it may be subject in service

Its chief disadvantages are due to its somewhat brittle nature under compression, its large cost when the conditions of work make it necessary to use long lengths, and to its being more difficult to work than most other kinds of timber

Oak.—Oak of several varieties are common in car work, viz. English, Stettin, and American, and their different values are too well known to require much remark, further than to say that the best classes of work admit only of the white quality being used. Red oak should always be avoided where the best results are sought. The weight of these different varieties vary from 48 to 58 lbs. per cubic foot, their tensile strength from 10,000 to 19,000 lbs. per square inch, and their transverse strength from 1200 to 1600 lbs. per square inch.

Pitch Pine.—The value of pitch pine as a framing timber is not generally understood, and therefore it is not much used in England When, however, consideration is given to the fact that its weight averages 48 lbs per cubic foot, its tensile strength 10,000 lbs. per square inch approximately, and its breaking strength as 82 to 100 in comparison with English oak, its value cannot be denied; besides this, owing to

its resinous nature it does not easily rot under varying conditions of moisture, and it is therefore of great value in floor framing. In selecting this timber care should be taken to exclude all sap and large knots, and include a large proportion of pitch, to which it largely owes its weight per cubic foot.

Ash.—This timber in framing is largely used where it is covered, and therefore protected from the weather, and it is also useful for such members as require to be bent into various forms Several varieties are known to the trade, but only such as are grown in hilly or mountainous districts are suitable for framing. Ash timber which is grown on low or marsh lands is deficient in both weight, tensile and transverse strength The best quality of ash known to the trade is termed second-growth white ash, it weighs on an average 48 lbs. per cubic foot, has a tensile strength of 10,000 to 14,000 lbs per square inch, and a transverse strength of 2000 lbs per square inch. Selections from this class of timber should exclude most brown qualities, and include at least 80 per cent of the second-growth white quality.

Of the timber used for outside finishing, teak has already been described, and it only needs to be added that where this timber is used for this purpose, it should be straight-grained stock, and not painted, but finished in its natural colour with varnish

Mahogany.—This timber is prized very highly for outside panel stock, and when well selected both as to grain, which should be straight, and as to seasoning, which should not be over-dried, the very best results are obtained It has the advantage over most other woods for this use, in that it does not readily check, split, or warp when properly put on the framing.

Canary Whitewood. — Following teak and mahogany, canary whitewood also stands very high as a suitable stock for outside panelling, and being much less in cost than mahogany, it is more often used In selecting panels from this timber, close attention is necessary to exclude all sap, which is readily detected by its colour, being when dry nearly white, and distributed in streaks along the edge of the boards, and to include only such boards as show an even yellow colour over the entire width and length of the same

Of the timber suitable for inside finishing, the four kinds stated in the list given above are very suitable, and most often used, viz. teak, mahogany, quartered oak, and ash. Each of these different kinds has been described except the quartered oak, which derives its name from the fact that ordinary oak cut on what is technically known to the trade as the "quarter" is called quarter sawn, or quartered oak The advantage of cutting oak in this manner is derived from the fact that the appearance of the grain is greatly changed, and a variety of light markings are irregularly distributed over the surface, which greatly adds to the beauty of the timber when finished The following simple rule will enable one to accurately select from a pile of this stock such boards as will give the greater variety of grain, viz. carefully inspect the ends of the boards as they lie in the pile, when it will be observed that fine

hair-lines of a light colour cross the ends of the boards at various angles; the nearer these lines approach a parallel position with the wide side of the boards the more variety and beauty of grain will be secured.

Seasoning of Timber.—The process by which timber is rendered suitable for use is termed "seasoning", and two different methods are used, either alone or in combination one with the other. The first process is termed natural seasoning in the open air, and the second process artificial seasoning or kiln-drying, and each process has for its object the evaporation of the sap from the pores of the timber, the first by a slow process in varying atmospheric temperatures, and the second by an accelerated process of much higher temperatures artificially produced The natural method consists essentially of storing the boards or planks as they are cut from the log in such a way as to admit of a free circulation of air on all sides The first step in this process is called "racking", and the second "pinning", by which is meant storing the stock in racks for a short period, and afterwards placing it in piles in which each course is separated by narrow strips placed 3 to 4 feet apart, it is then left in these piles for a period of time varying with the thickness of the stock in the pile, the time required on an average being one year for each inch in thickness of material When piled in this way one or two coats of paint on each end of the planks will be found an excellent preventative against checking

The true process of kiln-drying timber is so little understood in England that great prejudice is exhibited against all stock prepared for use in this way, at the same time, this process has great advantages, and when the most modern appliances are understood and used, the results obtained are second to no other method for seasoning timber

In the early developments of this process it was the rule to confine timber to be dried in rooms containing a large heating surface of steam pipes, through which was passed steam at a very high temperature. The result of this process was found to be very detrimental to the stock so treated, owing to the fact that the material coming into contact, in its more or less green condition, with the high temperature thus produced, the pores of the outside surface of the planks were prematurely closed, which confined the sap within the grain, and prevented the process of evaporation on which all true seasoning depends.

The modern method of kiln-drying timber widely differs from this practice, and in the present day drying kilns are constructed with a series of rooms in which the timber is placed, and which contain no piping of any kind, and consequently no steam to produce the extremely high temperatures which have proved to be so detrimental. In fact, the modern process seeks to embody as near as possible the conditions of natural seasoning, viz. air heated to a moderate temperature and circulated by means of fans through the various piles in the different rooms in a similar way that the piles would be subject in the open air.

Thus it will be observed that the modern process of kiln-drying timber is based wholly on the rapid circulation of moderately-heated air, and not on high temperatures confined in a small compass like an oven.

The best results from this process are obtained when the timber has been piled in the open air from six to eight months after being cut from the log before being placed in the drying kilns. Where this plan is observed, stock treated to temperatures varying from 120° to 180° rapidly circulated will be quite suitable for use in from three to five weeks' time, according to the thickness of the material

After the timber has passed through the mill, where it is cut to the desired shape, it is placed in the hands of the body-makers, and on completion of the framing, panelling, roofing, and fixing of the platforms, it is taken possession of by the painters and inside finishers, who are responsible for the general appearance of the car as the public see it

The car body has to be securely trussed to prevent it getting hog-backed and the platforms sinking. The trusses should be arranged so that they may from time to time be pulled up to counteract any tendency to sagging, and when pulling up the trusses the platforms should be jacked up to assist the pull.

The process of painting takes considerable time, as may be deduced from the following short description of the operation:—

Painting and Varnishing.—This is one of the most important steps in the production of a completely finished car, for on it not only depends the general appearance of the work as a whole, but the durability of all perishable parts as well

The various steps involved in the work of this department may be stated as follows Priming, filling, rubbing down, second priming, colouring, second rubbing down, decorating, and varnishing, all in the order named These various steps, with the number of coats in each, may be stated in the following scheme, which approximates as nearly as may be an average standard practice —

Priming—

First coat lead

Stopping all nail-holes and various other imperfections

Second coat lead

Second stopping of nail-holes and imperfections.

Filling.—

Four coats filling (sometimes called rough stuff).

One coat stain (sometimes called the guide coat).

Rubbing Down—This step consists of going over the car with a large block of pumice-stone and water, and with long sweeping strokes rubbing through the guide coat mentioned above. When the guide coat is entirely removed in this manner, if the work has been carefully done, the result will be a hard smooth surface, furnishing a good foundation for the succeeding step, viz second priming

Two coats of lead constitute this step, which together with further stopping, if found necessary, prepares the car for colouring.

Colouring.—From two to four coats of colour are required, according to circumstances. If the colour used is light or semi-transparent, four coats are necessary to produce a "solid" appearance. In all cases the last coat should have a proportion of hard-drying varnish, which,

when rubbed down with powdered pumice-stone and water, gives a hard bright surface on which to decorate, line, letter, and number

Varnishing—This step consists of two coats of hard-drying body varnish, the last coat being rubbed with powdered pumice-stone and water One coat of fine-body finishing varnish completes the work It is essential that in the last stages of the work as even a temperature as possible should be observed, 60° being considered essential to secure the best results

Materials.—The quality of the materials used in the foregoing work largely influences its character when completed. The grade of white-lead known to the trade as "genuine" should be used for all work which is intended to present what is known as a finished surface No. 2 white-lead, consisting of 12 per cent adulteration, may be used for all the rougher kinds of work

It is important that white-lead should be frequently tested to ensure that the quality is right The following test is the severest to which it can be subjected, viz A few ounces of lead are taken from a cask and placed on a metal sheet, a lighted match is then brought into contact with the lead, which is ignited and which burns until the whole is consumed If metallic lead alone is left, it proves the lead to be genuine, but if, on the contrary, any proportion of dross is associated with the metallic lead, the amount of dross represents the amount of adulteration to which the lead has been subjected

As to colours, those ground in turpentine by a responsible manufacturer have been found to give the best results, both from an economical stand-point and from the uniformity in the shade of colour that can be secured.

Those varnishes of the best manufacture only should be used, poor varnish gives but very poor satisfaction, so far as appearance goes, and its durability is equally unsatisfactory

General Remarks.—When constructing the car underframing, allowance must be made for the provision of trap-doors opening up over the motors, this is necessary in order to facilitate inspection and attention These traps should be provided with countersunk handles for lifting by The floor of the cars and the top deck, if of that type, should be provided with wearing strips; these serve the dual purpose of saving wear to the floor proper, and of keeping the passengers' feet dry. In putting in these strips, they should be laid in such a manner as to interfere as little as possible with the natural drainage and the sweeping out of the car. The platforms should also be covered in the same manner.

The ends of the platforms should be provided with steel dash-plates, on which may be mounted the head-light fittings, these plates are supported on wrought-iron posts. Projecting beyond the dash-plates should be fixed the buffer irons, attached to the end of the platform bearers. These are either of channel, angle, or T section steel, and may be pressed to shape between dies with a special machine in one heat.

The windows of the cars should be glazed with a plate-glass, usually about $\frac{1}{4}$ inch thick, set in with rubber

The doors at the end of the car body may be of the single or twin type. The latter, though convenient, are hardly so reliable in action as the single type The doors are slung on sheaves running on a track provided for them, and should be kept in position with guides.

The roof of a double-deck car, of course, has to be very much stronger than that of the single-decker. Provision has to be made not only for the weight of passengers to be carried, but for the strain consequent upon the use of a trolley standard some 5 feet 6 inches or 6 feet high. The ceilings employed may be either tongued and grooved in alternate coloured woods, or of a more elaborate class, bird's-eye maple veneer, or decorated mill-board. The latter is very popular, and is less likely to give trouble and is easier to clean than the veneer, and when dirty it may be re-decorated in any style required. Above the ceiling is a light roof of, say, ½-inch material, tongued and grooved, nailed to the hoop-sticks. On this is placed a layer of cotton duck, applied wet in a coat of white-lead paint This prevents the percolation of any water through the roof The upper-deck boards are then put on, these too being tongued and grooved The usual thickness of these boards is ⅞ inch.

The general practice for the top-deck seats is to employ the ordinary reversible garden type screwed down to the deck. The seating is of lath and space, and they do not readily hold the rain There are, however, a number of "dry seats" employed too numerous to mention For the inside seats, which are generally of the longitudinal type, a variety of forms may be adopted, the most prominent being the lath and space of alternate coloured woods; these are sometimes covered with removable carpet Also we have the perforated veneer, the upholstered or cushioned seat, the upholstered or woven-cane spring-back seat, &c.

The appearance of a modern car is greatly augmented by the use of embossed mouldings, carving, and other decorative devices, and we illustrate in fig. 1166 the interior of a Liverpool standard car, as constructed by the Electric Railway and Tramway Carriage Works of Preston. This illustration shows the improved roof construction introduced by these makers into car body design, the chief advantages gained being the greater air capacity of the car interior, and the better facilities for ventilation. This design has now been adopted as a standard by nearly all British car builders,

CHAPTER II

ELECTRICAL EQUIPMENT

Motors.—The design of a modern series-wound tramway motor is a much more difficult problem than is generally realized, owing to the very small space that is available under a car, the limited room on the car axle (even with a 4-feet-8½-inch gauge), and the heavy duty expected of the motor, combined with the exposed position in which it is placed. It is not surprising, therefore, since the introduction of electric traction, motor design

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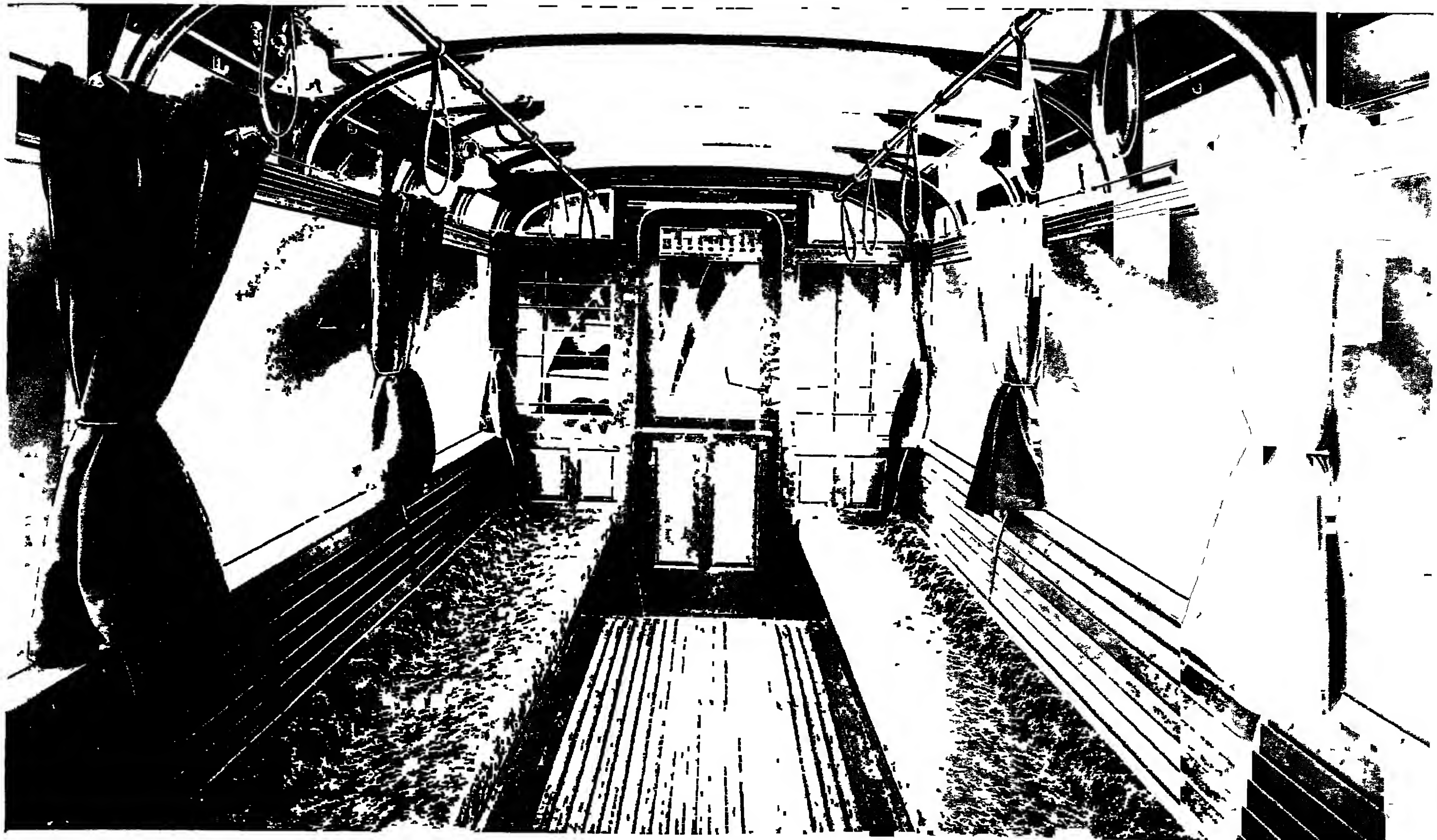

Fig 1166 —INTERIOR OF LIVERPOOL STANDARD CAR

Fig 1167.—Axle Gear and Gear-Case

has undergone many important changes, each advance being made after actual experience had proved the then existing methods both faulty and unreliable. Each change has been in the direction of rendering the motor impervious to water, dust, vibration, and load variation

Many methods of transmitting the power from the motor to the car axle have been tried, which at the same time reduced the speed of the car axle to some fraction of the armature speed In order to get the required output from the motor, and to keep its dimensions within possible limits, a considerable gear reduction has to be obtained Belts, chains, bevel-gears, worm-gears, spur-gears have all had their trial, and finally it has been universally accepted that the spur-gear keyed and clamped on to the car axle itself, and meshing directly with a pinion-wheel directly attached to the armature shaft, offers the best solution to the problem. Fig 1167 illustrates the modern gear-wheel both before the teeth are cut and after. The same illustration shows the gear-case or housing, which enables the gear and pinion wheels to be run partially immersed in grease. The most suitable material for the gear-case is malleable cast-iron. The gear-wheel should be manufactured from a high grade of cast-steel with a view to strength

and long life. It should be cast in halves, and after the faces of the halves are accurately machined, and the hub bored to the proper size for the car axle, the halves should be brought together, and the teeth cut by special machines from the solid metal A keyway is cut in the bore for the axle key.

The pinion-wheel should be of softer material, usually being of forged steel, the teeth being cut from the solid as in the case of the gear-wheel

We illustrate in fig. 1168 a No. 25A motor built by Dick, Kerr, & Co, Limited, of Preston, Lancashire. We may take this motor as an example of the standard tramway motor of the day, and in the short outline of the construction of a motor given below we shall have special reference to this machine. Great similarity exists, however, in the general design of all modern tramway motors, and therefore our remarks will to a great extent

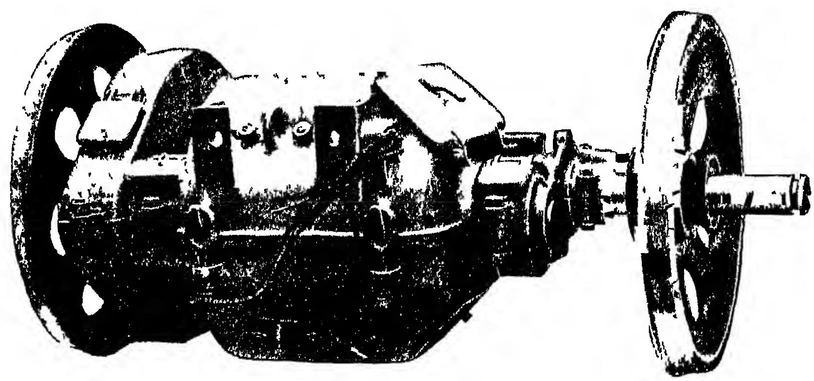

Fig 1168 —View of 25A Motor mounted on Axle

apply to other motors, two of the leading types of which we illustrate in figs. 1169 and 1170 The machine we are describing will have an output of somewhere about 1 horse-power for every 80 lbs of its weight, and will be quite dust-proof and practically water-tight, while at the same time it is of the utmost importance that the ventilation of the machine is as liberal as it is possible to make it, both as regards the armature itself and the motor casing

The motor frame consists of two bowl-shaped steel castings, on to which are cast bearing-boxes for the armature and car axle As this motor casing fulfils the part of magnet yoke, as well as being the mechanical frame of the machine, the steel should be of low magnetic reluctance.

To the frame are bolted the pole-pieces, arranged two in each half of the motor case, which is divided horizontally in line with the centre of the armature shaft. These pole-pieces are built up of laminated steel punchings, a precaution necessary to prevent heavy eddy currents and consequent loss in efficiency.

The pole-pieces are so constructed that they hold in position the field-coils surrounding them. It is particularly important that the coils be held sufficiently firmly to prevent the vibration of the motor chafing the insu-

lation. The coils are generally protected from the edge of the pole-pieces by a gun-metal frame. In some type of motors only two of the poles are directly energized by coils, the remaining two being merely consequent

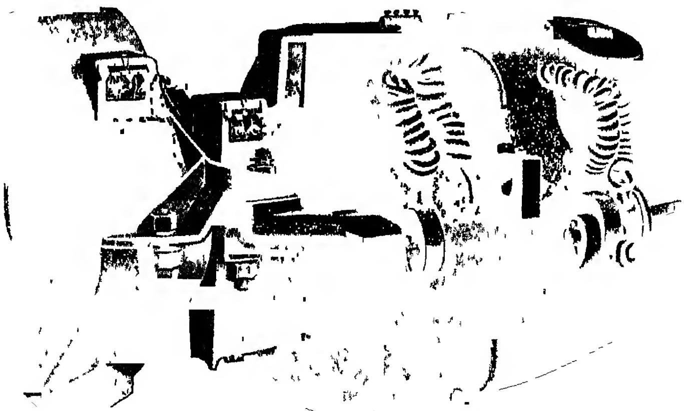

Fig 1169 —Westinghouse No 49 Tramway Motor

poles. This practice is, however, quite the exception, and most modern motors have four salient poles

The field-coils should be heavily insulated with water-resisting material, and with a view also of withstanding the vibration to which they are bound to be subjected The practice of making all the field-coils interchangeable

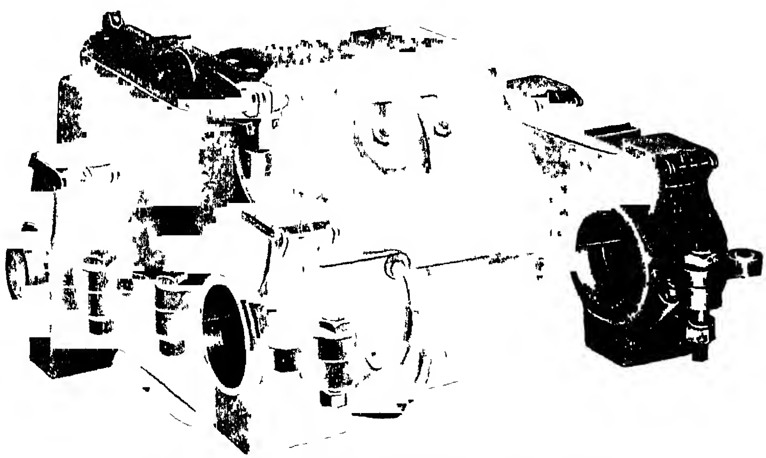

Fig 1170 —British Thomson-Houston 25 H P Tramway Motor

is to be highly commended as against employing right- and left-hand-wound coils, necessitating extra spare parts, and always courting the possibility of mistakes.

The armatures are almost universally of the slotted-core type, the core being built up of thin sheet-steel punchings, each separated from the other by a thin layer of japan, or other insulating medium, in order to prevent

excessive core losses. The punchings are carefully annealed, and every endeavour is made to give the armature core a high magnetic conductivity and low hysteresis. The punchings provide a hole in the centre for the armature shaft, and for the key which is fitted into the shaft The punchings are also provided with holes stamped in them, these have a symmetrical relationship to the keyway, so that when arranged on the shaft they all come opposite one another. This provides the core with the necessary ventilation, which, together with the special spacing discs, placed at intervals, allows a sufficiently free passage for the air to ensure proper cooling.

The commutator is built up on a hub, which is fitted and keyed to the armature spindle. The copper employed is usually hard-drawn or drop-forged, each bar being insulated from its neighbour by pure mica strip, and from the frame by a mica compound moulded to suitable shape. The number of bars employed depends, of course, entirely on the design of the motor, varying considerably with different makers, sizes, and speeds Tramway motors are presumed to be worked with a pressure of 500 volts, but the motors to be of any practical service must operate equally satisfactorily with a 10-per-cent variation from the normal voltage Also, a tramway motor must run sparklessly in either direction from no load to 50 per cent overload without the position of the brushes being changed In the best tramway motors of to-day these conditions are fully met with absolute success. The commutator bars should have sufficient depth to allow the wear and periodical turning up necessary, and an allowance of 2 inches reduction in diameter at least should be provided for this purpose

The brushes should be held on to the commutator by springs, giving a sufficient pressure to ensure the brushes not jumping from the face of the commutator over bad rail-joints, crossings, &c The springs should be arranged to take up the wear of the brushes automatically Some designers favour the practice of employing two brushes in each brush-holder, while others consider one brush more satisfactory Theoretically, the use of four brushes per motor will equalize the wear on the commutator if the brushes are properly staggered It is quite a question, however, in practice, whether this end can always be attained The carbon employed for brushes is in course of manufacture squirted or moulded under considerable pressure, and should be homogeneous right through; the brush is coppered to increase its conductivity. It is generally considered good practice to give the brushes a slight slope, so that they do not sit absolutely radially on the commutator It has been found, if they are placed square on the commutator (*i.e* with no toe and heel), with the constant change of direction of the motor they tend to chatter in the brush-holders. The brushes should be sufficiently hard not to dirty the commutator, but not hard enough to score it. If the carbon be too hard the brushes will not only get very hot, but will chip at the edges and cause sparking.

The armature coils should all be wound on proper formers, thus ensuring that each one is interchangeable with the other. They are made of copper having 100 per cent conductivity, and the copper should

be of a sufficiently pliable nature to ensure it not fracturing in the process of winding, and fixing on the core, or from subsequent vibration when in service The coils are wound with cotton-covered wire, which, after it is wound on the former, is dried in an oven After this it is dipped and dried alternately in special insulating varnish till sufficiently impregnated. The varnish should when dry be elastic, and have no tendency

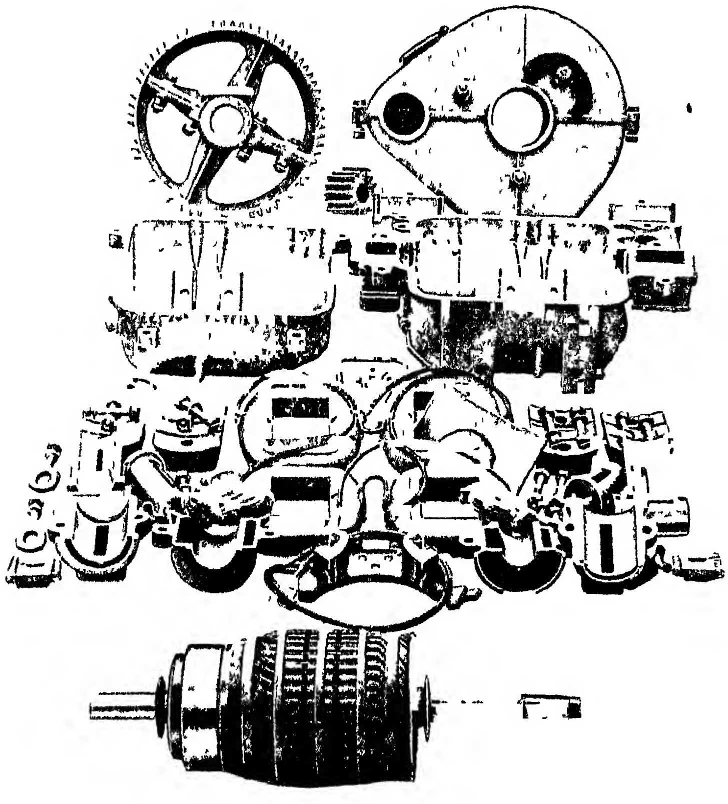

Fig 1171 —Parts of No 25 Type A Motor before Assembling (Dick, Kerr, & Co)

to crack when the coil is being placed on the armature core The coils, before being forced into the slots of the armature core, are further insulated and protected by mica, press-board, and linen, then taped, and again dipped in varnish and dried After all the coils are in position the connections are carefully soldered into the slits in the commutator bars provided for that purpose. It is always advisable that the coils of an armature should not project above, or even come level with the face of the core, and in addition to this it is good practice to make the flange of the end-plate of the core of greater diameter than the core itself. This precaution will

minimize the danger of injury when the armature is being handled on the floor of the car shed. In the illustration fig 1171 we show all the parts of a motor before assembly, and in the next illustration, fig 1172, we show the same motor assembled, but with the lower half let down for inspection. It is very important that the motors are arranged so as to be capable of being opened up while mounted on the car axle, with the armatures either suspended to the top half, or resting in the lower half, as may be found most convenient for the particular form of inspection required.

The rating of tramway motors is, of course, quite different from that of generators and stationary motors, the conditions of their operation in

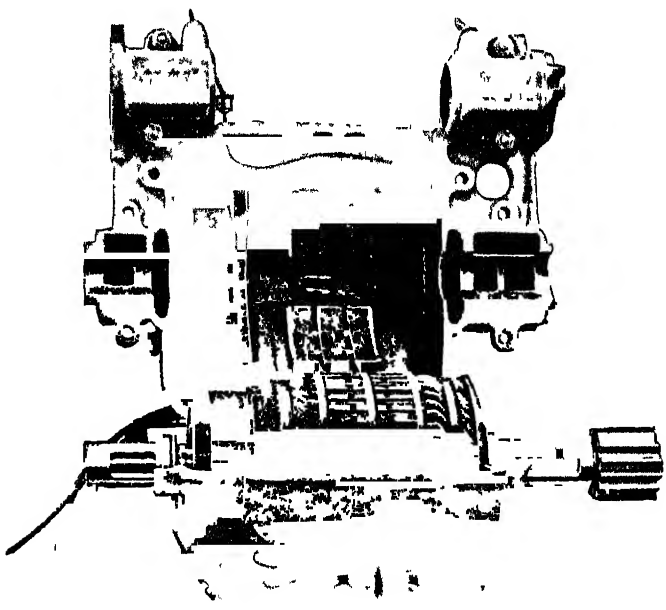

Fig 1172 —No 25 Type A Motor Assembled, open for Inspection

service requiring that they shall only develop their full-load horse-power for short periods at a time A standard rating has, by common consent, been accepted by American manufacturers, and this rating has been generally accepted in this country as well, the specification of which runs as follows —"After one hour's continuous run at the full rated load the temperature of any part of the motor windings, taken either externally or internally, shall not exceed a rise of 75° C above the temperature of the surrounding atmosphere taken at a distance of not more than 2 feet from the motor, subject to the temperature of the atmosphere being not more than 25° C. The tests to be made with the commutator cover open in order to approximate to the actual conditions of service as regards heat dissipation." It is convenient to show the efficiency, tractive effort, speed, and horse-power obtained by the various ampere inputs by means of curve sheets, one of which is reproduced in fig 1173, representing a 35-horse-

power motor built by Dick, Kerr, & Co., Limited, of Preston, Lancashire. We further reproduce the curves of the British Thomson-Houston 25-horse-power motor (fig. 1174) and Westinghouse No 49 motor (fig 1175)

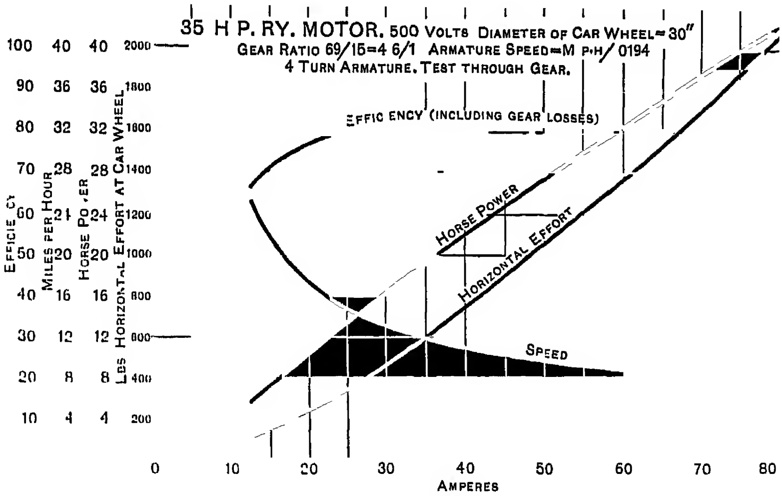

Fig 1173

The curves are obtained by actual observation of the performance of the motor, and are plotted to scale at the various ampere readings taken It is, of course, seldom that two or more motors will show exactly the same curves, and therefore, if the curves are to be of any practical value, several motors should be tested and the representative curve sheet of that particular type of motor should be the mean of the results obtained.

The efficiency curve is plotted from values obtained from the tractive effort and speed, and by comparing these with the electrical input. For the sake of convenience, and to facilitate comparison, this relationship is expressed as a percentage The electrical input expressed in horse-power is the product of volts and amperes (*i e.* watts) divided by

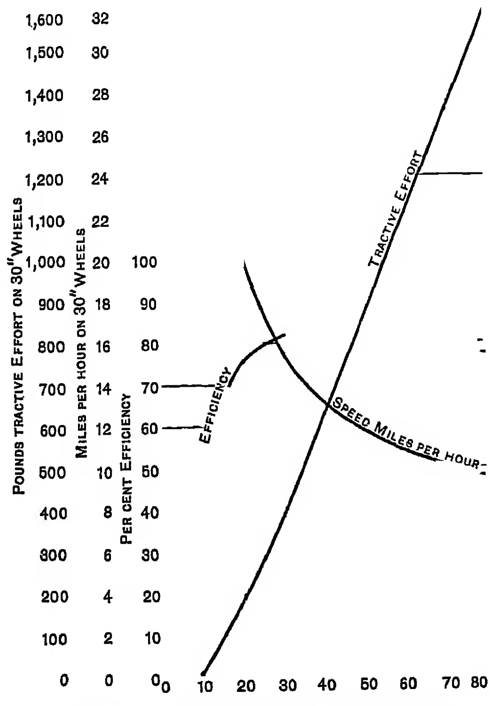

Fig. 1174.—Curves of B.T.H 25-H -P Tramway Motor

746. The mechanical horse-power output is found by multiplying the tractive effort in pounds by the speed in feet per hour, and dividing the product by 33,000 × 60, the value of a horse-power-hour in foot-pounds

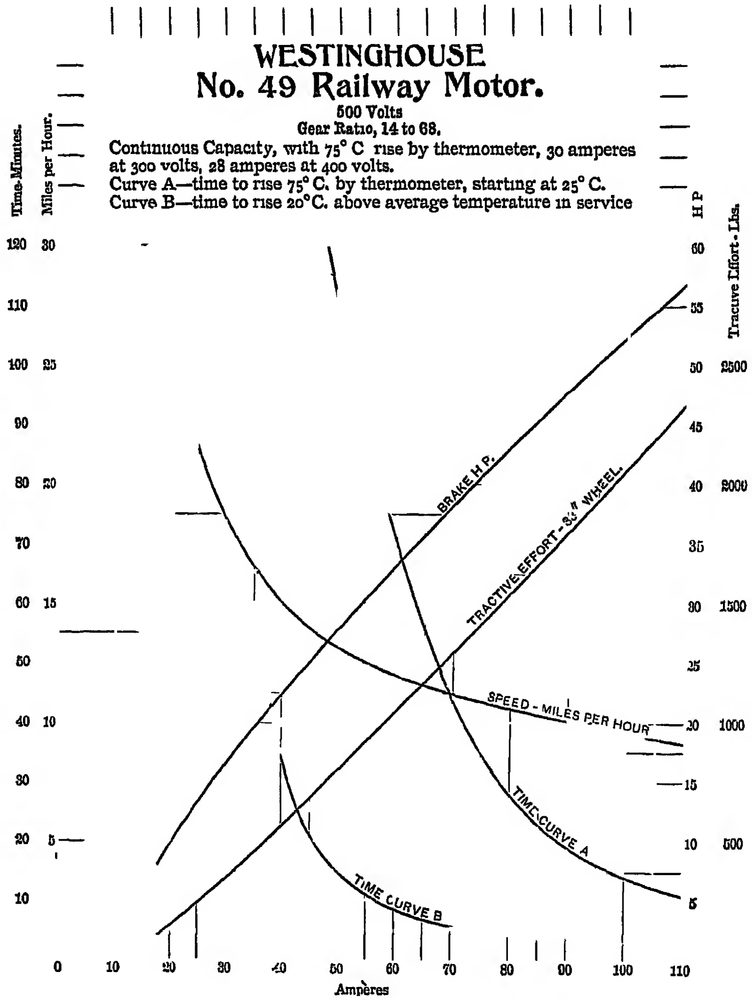

Fig 1175

per minute. For example, take the curve shown in fig. 1173, we get the following expression at 40 amperes input:—

$$\frac{750 \times 11 \times 1760 \times 3}{33{,}000 \times 60} = 22 \text{ horse-power.}$$

The electrical input is equivalent to—

$$\frac{40 \times 500}{746} = 26.8 \text{ horse-power.}$$

We therefore get the efficiency expressed by—

$$\frac{22 \times 100}{26.8} = 82.1 \text{ per cent approximately through gearing.}$$

For tramway purposes we may very safely figure the tractive effort required for cars on the level upon the following basis.—For cars of approximately 8 to 12 tons (of 2240 lbs.) allow 28 lbs for every ton weight of car loaded. We may take, for example, an ordinary double-deck four-wheel car weighing loaded 10 tons This gives us $10 \times 28 = 280$ lbs. To obtain the tractive effort required by the same car ascending a grade, we must add to the above figures the value obtained by expressing the grade in a percentage, and by taking that percentage of the total weight of the car in pounds. Thus, assuming the grade is 1 in 15, this expressed as a percentage is 6.66 per cent We get therefore an additional tractive effort required of $\frac{10 \times 2240 \times 6.66}{100} = 1491.8$ lbs, to which we add the 280 lbs required on the level, giving a total of 1771.8 lbs This sum, divided by the number of motors operating the car, will give the tractive effort required of each, which in this particular case is 885.9 lbs per motor. Possibly a less roundabout method of obtaining approximately the extra tractive effort required for ascending a grade is to express the grade as a fraction instead of as a percentage. Assuming the same conditions as above, we get the following —

$$10 \times 2240 \times \frac{1}{15} = 1493.3 \text{ lbs.}$$

By reference to the curve again, we see that each motor will give 885 lbs pull at $10\frac{1}{2}$ miles per hour.

Controllers.—Passing from the motors, we may next consider the controllers, bearing in mind the important and responsible functions which they perform. They regulate not only the direction of rotation of the motors, but the various speeds at which the car is to travel They may be called upon several times a minute to break circuit when the two motors are momentarily developing 40 or 50 per cent overload, and are in continual operation throughout the day. When we come to consider the size of a controller, with its many functions, and combinations obtainable, and its incessant use, it is a matter of wonder that such a relatively perfect apparatus has now been produced.

We will not enter into a history of the many devices which preceded the modern controller Suffice it to say that the earlier attempts were based generally upon a rheostatic control only, and one controller situated under the car with its resistances was worked from both platforms by mechanical means The inefficiency of controlling two or more motors by rheostatic means soon became apparent, and it was then that the more modern series-parallel control was introduced, the diagrammatic connections being relatively shown in fig 1176. This eliminates a very large percentage of the losses hitherto sustained in the resistances, and this method has now been adopted by all makers. It gives two

speeds in which no resistance is in circuit—(*a*) both motors in series, and (*b*) both motors in parallel. These two positions are called the running notches; the speeds in which resistances are employed, being termed the accelerating notches, are only to be used to speed the car up to the running notches.

Some makers have introduced notches after the series and parallel running positions, in which the fields are shunted by a portion of the resistances, the effect being, of course, to put up the speed. This practice has, however, not found great favour, chiefly, we believe, on account of the difficulty in getting the motormen to desist from using these notches when the motors are heavily loaded, and so causing commutating troubles.

In comparing the relative merits of controllers, one must consider the following points as being essential to satisfactory results:—Chiefly, of course, the controller must handle the currents for which it is designed

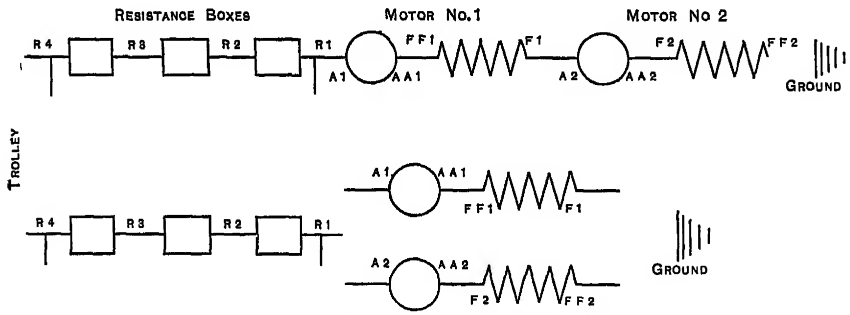

Fig 1176 —Series-Parallel Controller Connections on Running Notches

without rapid depreciation to the wearing parts. These, together with the parts liable to damage, must be easily removable and cheaply replaced Every part of the controller must be easily accessible for cleaning and adjustment, and must be perfectly fire-proof Owing to its exposed position on the car, the controller must be absolutely rain-proof. In order to prevent rain getting through the cover where the spindles come through, a ring, shaped like an umbrella, is shrunk on the spindle, and this drains into a gutter of horse-shoe shape around the spindle, which in turn drains on to the top of the controller body casting, and from there finds an outlet through holes drilled for the purpose to the exterior of the controller.

There are various methods of breaking the arc so as to avoid damage to the contacts. The principal means employed are either by breaking the arc in a strong field produced by an electromagnet, or in a strong field induced by a series of solenoids situated between each contact finger. A third method is by breaking the arc in several places simultaneously We illustrate three representative types of controllers in figs. 1177, 1178, and 1179. In the case of the magnetic blow-out the magnet is energized during the whole time that the controller is passing current, and the disruptive effect is limited by the permeability of the iron in the core. The solenoid coils are cut out of operation on the two running notches, only being in operation when the current is being broken This

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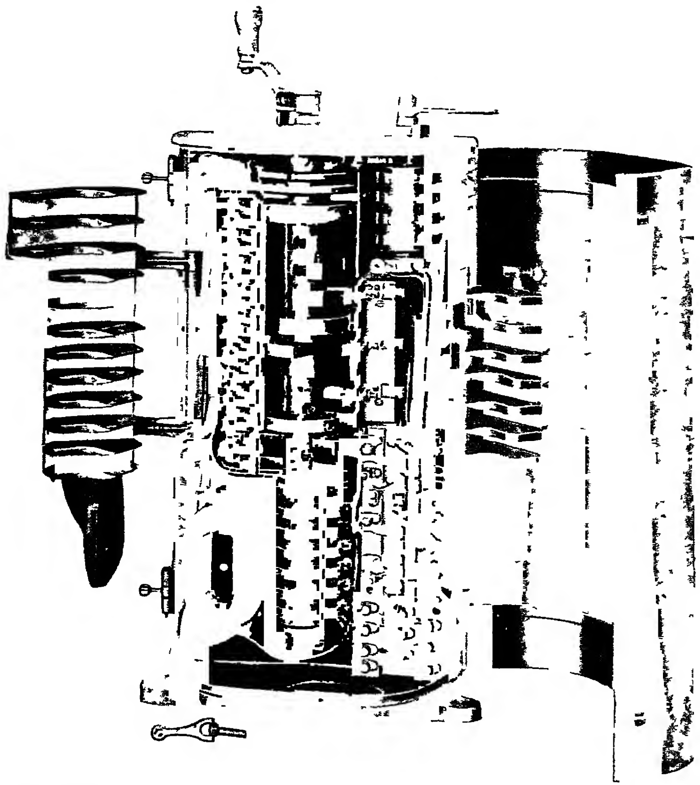

Fig 1177 —British Thomson-Houston Co (B18)

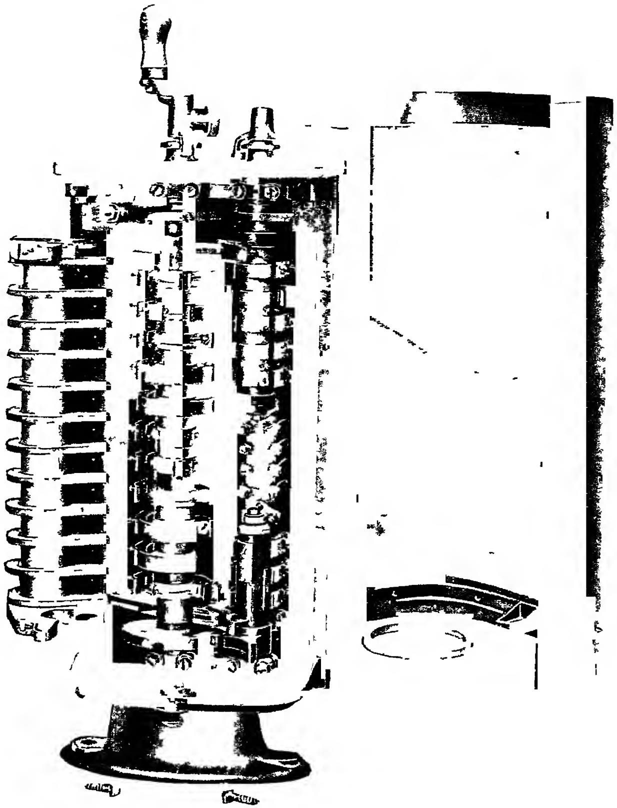

Fig 1178 —Dick, Kerr, & Co (D B 1, form C)

ELECTRIC CONTROLLERS

is rendered possible by the instant creation of a field when current passes through the coils, the field being proportional in strength to the current flowing round the coils at the moment of breaking circuit.

Messrs Dick, Kerr, & Co. have recently introduced another form of magnetic blow-out upon an entirely new principle, and as it is likely to play a very important part in the development of controllers and arc-breaking devices generally, it is worthy of some detail description. In place of the solenoids hitherto adopted by this company they now provide

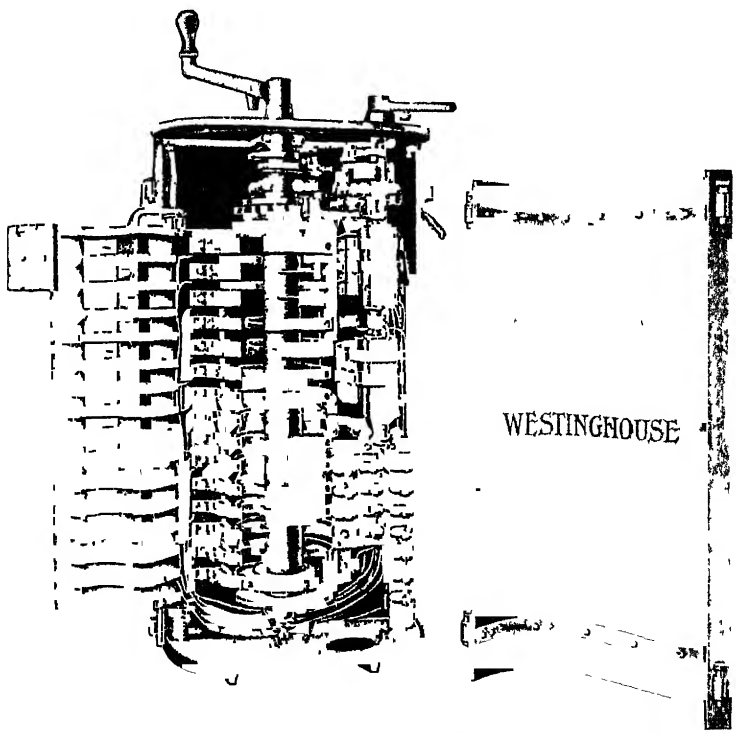

Fig 1179.—Westinghouse Controller (No 90)

magnet core running the whole length of the controller, this core being energized by windings in series with the motors Entirely encircling the windings are placed thin copper rings, one ring for each controller contact, and each ring divided from its neighbour by an insulating division A representation of this controller is given in fig 1178, and the device may there be seen swung back from its normal position, which is in close proximity to the contacts.

As soon as an arc forms between the contact and finger the field produced by the coil draws the arc towards the copper shield, but at the same time forces it round the copper ring so that the arc is lengthened and attenuated until a complete rupture occurs. While to all intents and purposes the rupture is instantaneous, the arc is not snapped out in such a manner as to endanger the windings of the motors in any way, and,

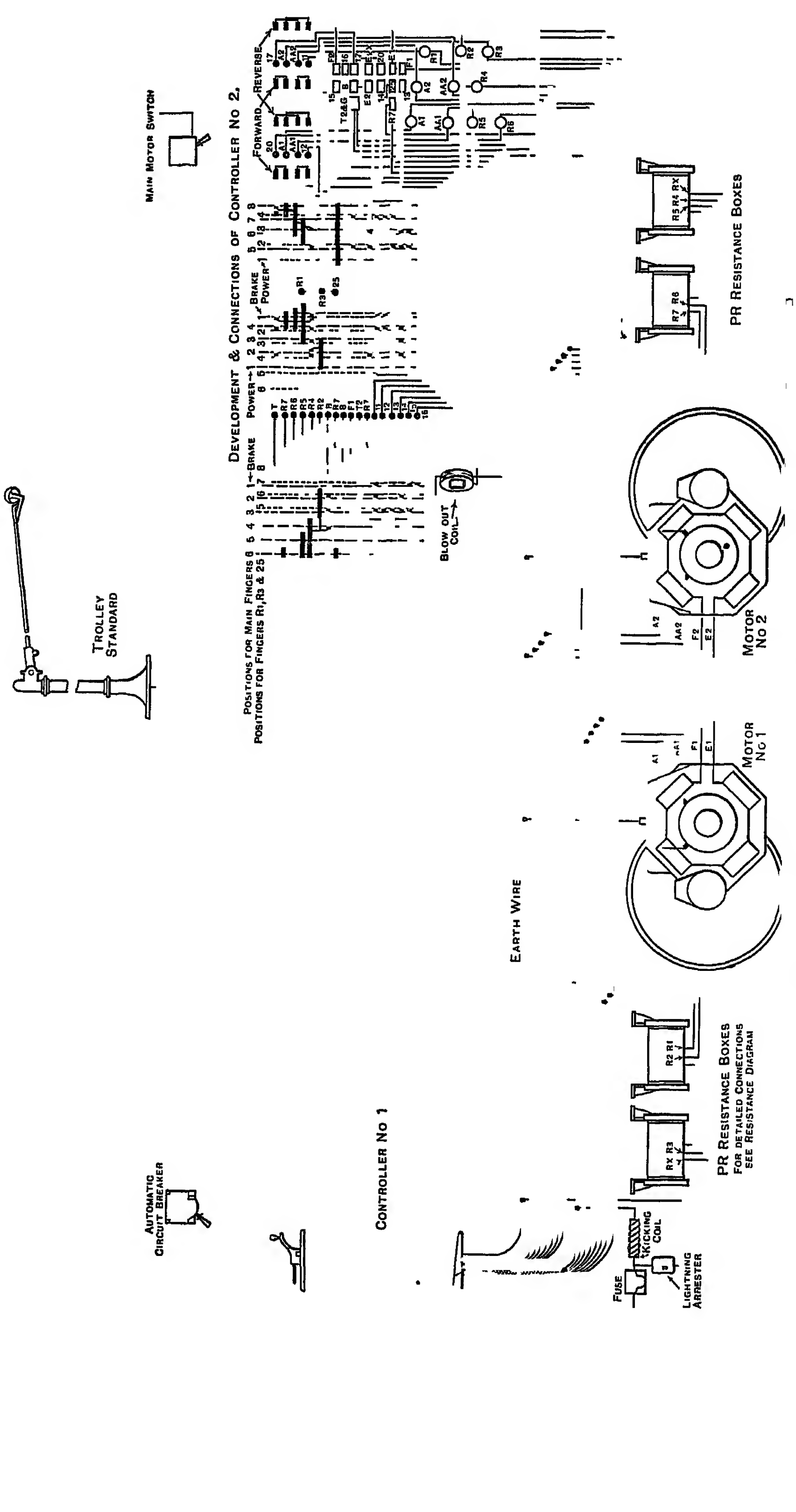

Fig 1180 —Development of Controllers arranged for Electric Braking B T H Co B 12

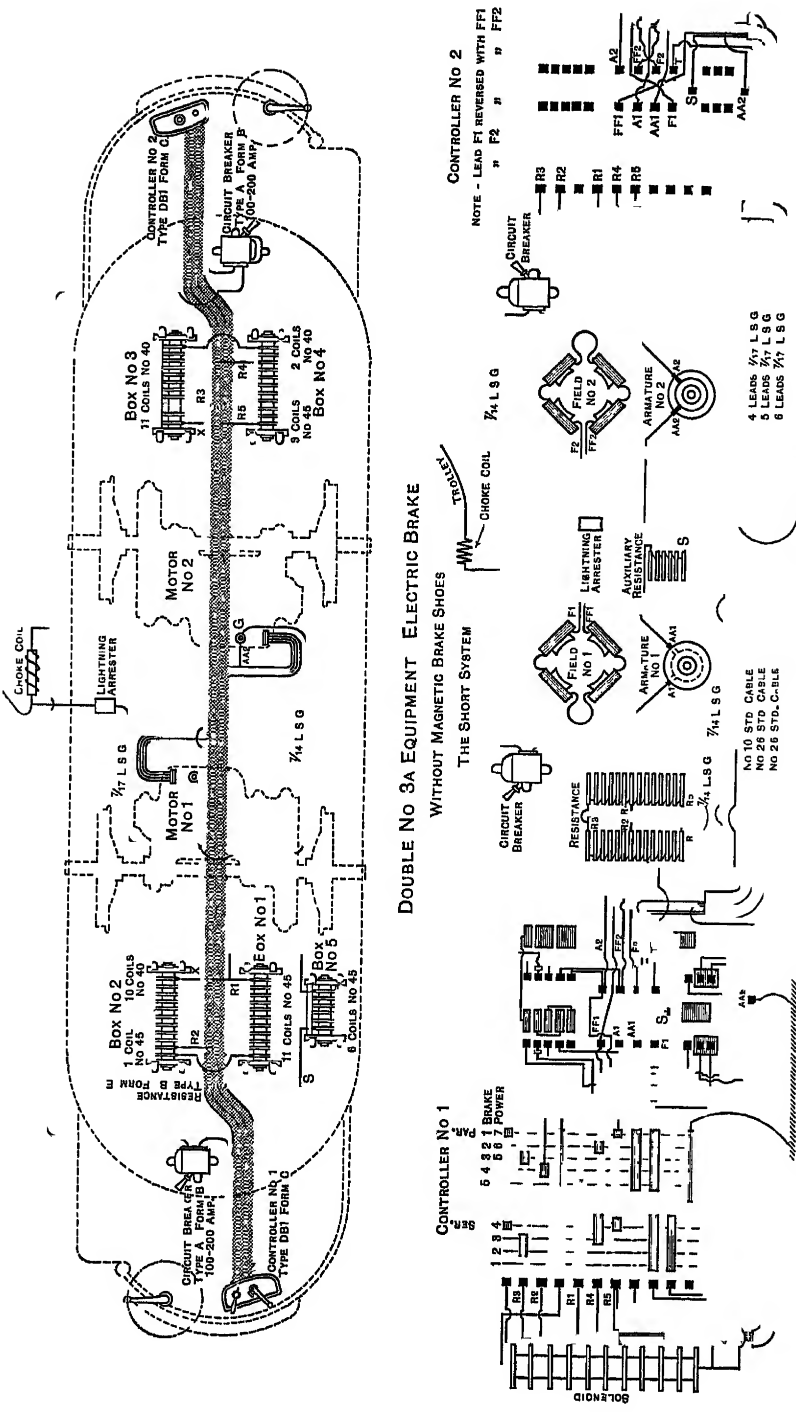

Fig 1181 —Development of Controllers arranged for Electric Braking D K & Co D B 1, form C

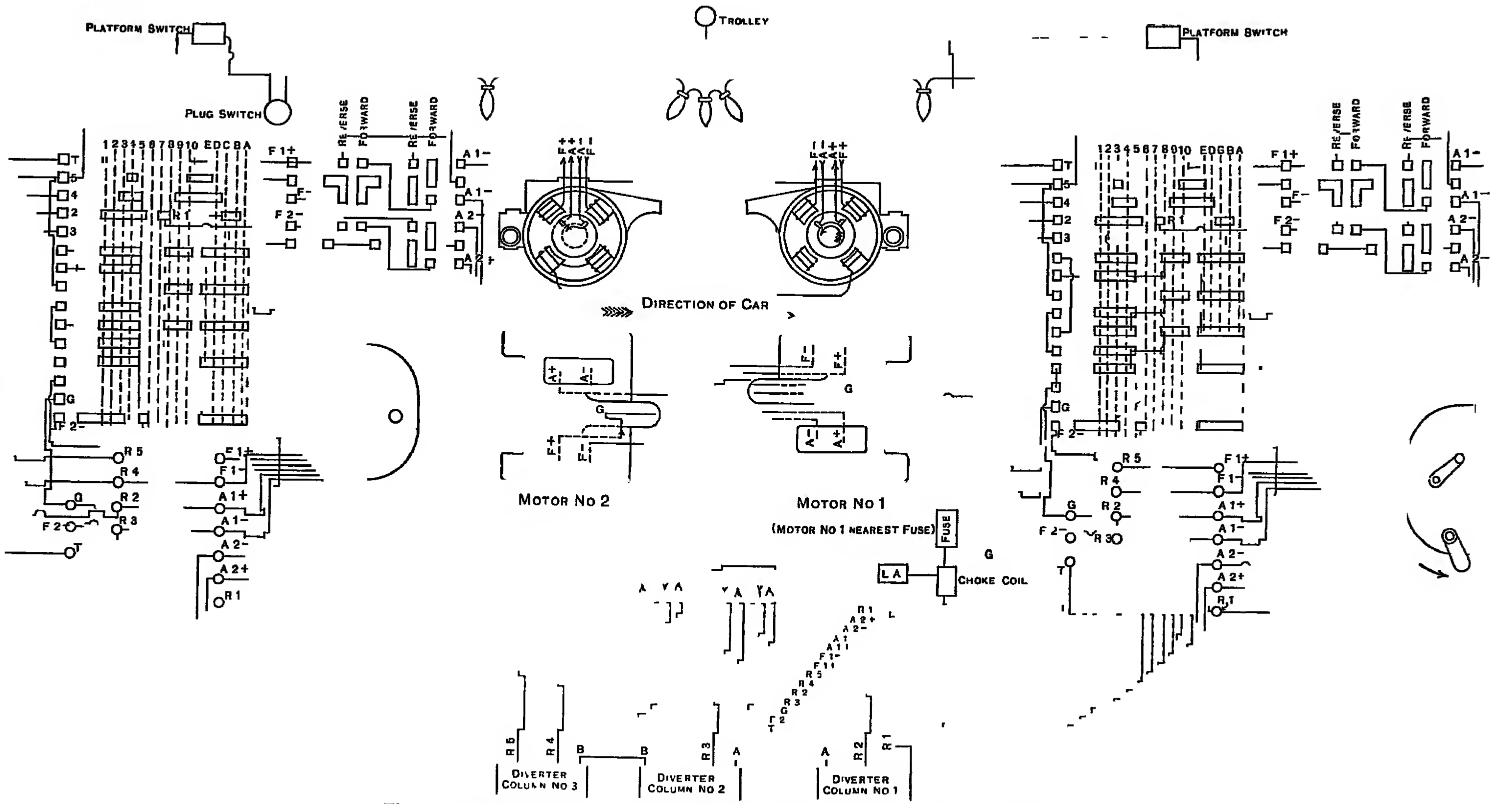

Fig 1182 —Development of Controllers arranged for Electric Braking Westinghouse, No 90

curious as it may seem, no appreciable deterioration to the copper rings around which the arc flows can be observed after many repeated ruptures. Controllers with this device have now been in use for considerably over a year in large numbers, and their success has led to this principle being adapted to circuit-breakers, motor-starters, and other electrical devices where destructive arcs are likely to occur.

This controller embodies another somewhat novel feature, in that the electrical brake notches overlap the power notches, and this feature, it will be readily seen, allows for a given total of power and brake notches a greater distance on the controller from notch to notch, or in other words, the thirteen notches—*i.e.* seven power, five brake, and off position—do not

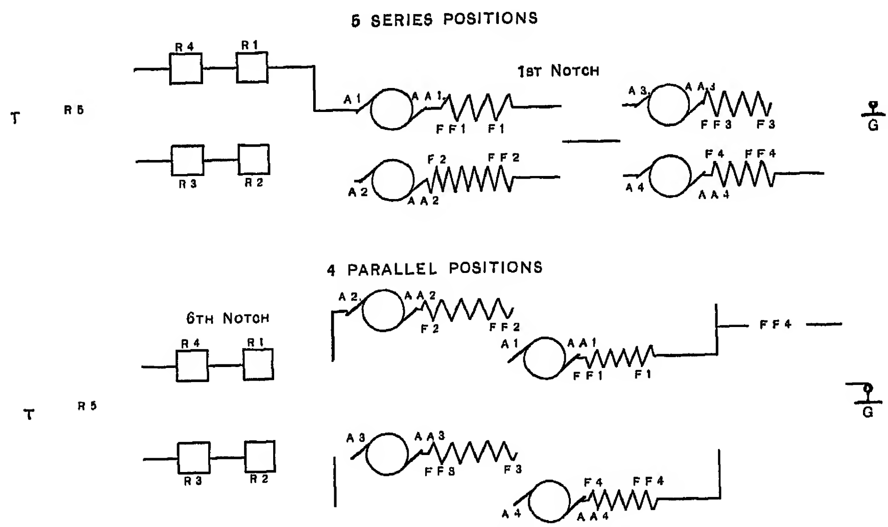

Fig 1183.—Quadruple Equipment Motor Connections

have to be crowded into the usual 180° available, and this has the effect, among other things, of reducing the size of the controller very considerably.

We reproduce the wiring diagrams, and development of three well-known types of controllers, from which can be traced the actual connections made on each position or notch in fig. 1180, B 18, fig. 1181, D B 1, form C, fig. 1182, No 90

In handling four motors on a car it is usual to employ special controllers The combinations can be made so that the car starts with two motors in parallel in series with two other motors in parallel, the resistance being cut out step by step in the usual manner. The next change in the grouping of the motors places them all in parallel, and the car is brought up to its maximum speed by cutting out the resistances which have again been reinserted. Fig. 1183 shows the connections on the series and parallel notches

It is general nowadays to construct all controllers with a braking arrangement, which we will deal with under the heading of brakes.

The motion of the controller handles must be free, but sufficiently

positive in action over the positions to ensure the motorman resting properly on the notch, otherwise injury to the contacts will ensue.

The mechanism of the controller should also provide that the driving handle is locked, and cannot be used unless the reversing handle is at the "ahead" or "reverse" position, and that the reversing handle cannot be moved unless the driving handle is at the "off" position In addition to this, it is a great advantage to arrange that neither handle can be removed from the controller unless it is at the "off" position

There should be only one pair of handles for each car, and these must be changed from end to end. All handles for the same type of controller should be interchangeable.

Every controller should be so arranged that either of the motors may be cut out of operation, and the car worked on the remaining motor, and this should be done by disconnecting the motor in the controller on the positive side of the armature connection. When cutting it out on one controller it is best, though not necessary, to cut it out on the other at the same time, in case this is forgotten when the other controller is put into use.

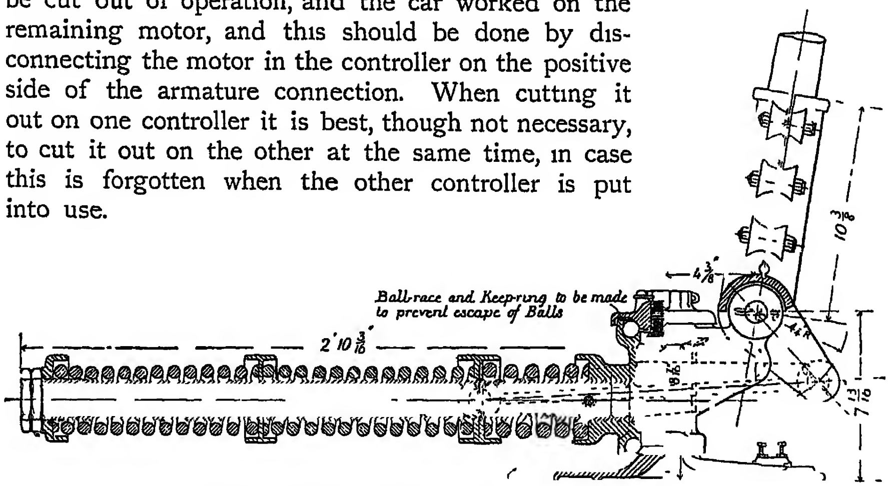

Fig 1184 —Single-Deck Trolley Base (Dick, Kerr, & Co, Ltd.)

In starting the car with one motor, it must be remembered that the full voltage is being put across it and the resistance in circuit, and due care in driving must be observed.

Resistances.—Intimately connected with the operation of the motors and controllers are the resistances, or rheostats A set of car resistances is generally made up for the sake of convenience into two or more boxes, or frames, to facilitate the disposition of them in the rather limited space usually procurable. They are placed under the car framing or platforms, and occasionally under the car seats, in properly fire-proof lined boxes, which must be carefully ventilated. The resistances must be able to withstand vibration, wet, heat, and opportunity for surface leakage must be reduced to a minimum. The design should be such that the heat is quickly dissipated. The material of the conductors should preferably not vary to any great extent in resistance with change of temperature, otherwise a hot resistance will mean an unpleasant and jerky acceleration of the car. Oxidation of the material should not occur under the conditions of service.

Trolleys.—We will next turn to the trolley or collecting arrangement. The type adopted depends on the style of car. For single-deck cars there is very little to be said, and the trolley may be of simplest construction. Fig. 1184 shows a trolley of this type, which may be taken as representative of its class.

With either single or double deck trolleys it is important that the movement of the arm is free both up and down, and around the central pivot, so that the variations of the line-work may be followed by the

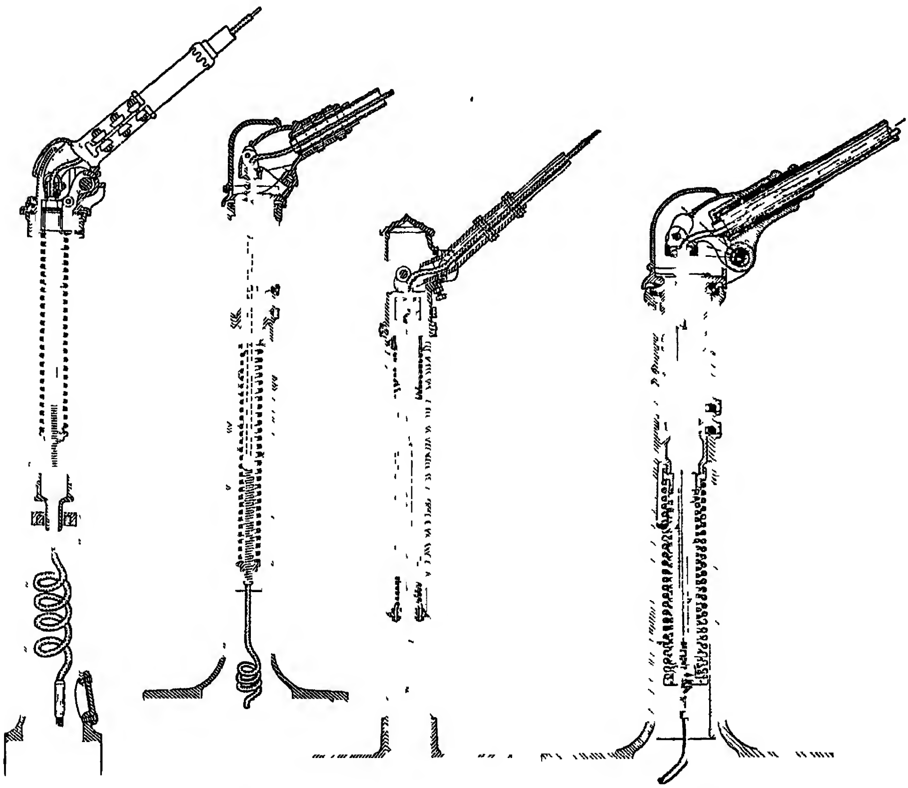

Fig 1185 —Various Types of Enclosed Spring Trolley Standards

trolley-head Also that the pressure of the head on the line at the varying heights may be nearly constant. The tension employed for centre-running wires may be from 15 to 20 lbs., and for side-running wires from 22 to 26 lbs., measured at the trolley-head at a maximum height of the trolley wire. In order to protect the wire and the guard-wires all trolleys should be provided with adjustable stops preventing the head from rising above a predetermined limit.

Considerations concerning the design of the double-deck trolley are somewhat complex. The body and pole of the standard must be carefully insulated from the live conductor for the protection of the passengers; and

as a further precaution the standard itself should be connected electrically to ground, preferably through a device which will indicate if there is any leakage going on. This condition of insulation renders it imperative that no rain can find its way into the pole or standard, and also that there is no possibility of the insulated cable running down the pole and standard becoming chafed, or otherwise mechanically injured. To prevent the cable being twisted a stop is provided, limiting the swing of the pole to nearly one revolution. Some of the standards have a rubbing contact enabling the stop to be dispensed with. This practice is, however, far from general, and we may take it therefore that so far an arrangement of this kind has not been proved in actual service to be of any material advantage.

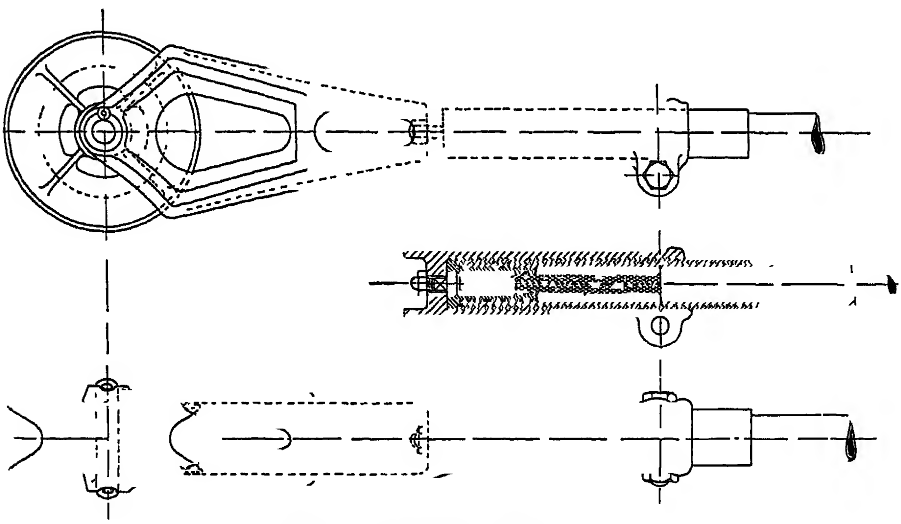

Fig 1186 —Trolley Head—Straight Running

Trolley standards with external springs were almost universal at one time, but are now almost entirely superseded.

It has never been doubted that the enclosed spring standard is more elegant and more cleanly. It was, however, a matter of some difficulty to get out a satisfactory article, and many years were spent by manufacturers in experimenting. The double-deck car being almost unknown in America, in this instance our home manufacturers had no previous experience to go upon. To be successful the mechanism of the standard must be easily got at for repairs and adjustment, it must be simple, and of reasonable dimensions At the present day there are quite a number of different types, most of which may be counted as satisfactory, and we illustrate in fig 1185 (*a*) B.T H., form B 2, (*b*) Estler, (*c*) Dick, Kerr, & Co., type T.S., (*d*) Blackwell, type S., a selection of four kinds Of trolley-heads there are a very large variety, and it would be impossible to note in the space available here one-quarter of them, each possessing some distinctive features of its own. We will therefore confine ourselves to illustrating (fig. 1186) an example of the straight-running type of simple

design. A side-running trolley-head has already been shown in fig. 925, page 4.

The trolley wheels should be of moderate diameter, and grooved to suit the size of wire and type of frogs, crossings, &c. They can be fitted with removable bushings filled with graphite, which may be replaced

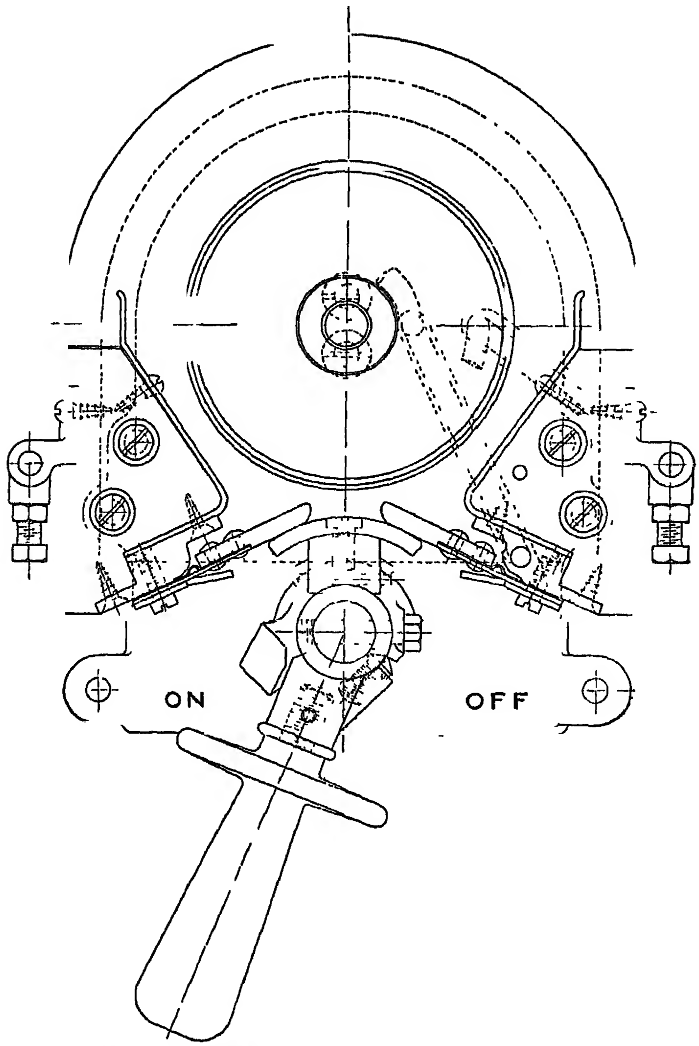

Fig 1187 —Dick, Keir, & Co.'s Circuit Breaker, Type A 60, form D

several times during the life of the wheel Precaution in designing is sometimes taken to prevent the rim falling off when the wheel is badly worn. Radiating webs from the boss to the flange are cast on the wheels, and these effectually prevent the flange from falling.

Accessories.—Each equipment should be furnished with two main switches for breaking the current in case of emergency, and for the general pro-

tection of the shed staff when cleaning or adjusting the controllers, &c. One of these should be placed at each end of the car within easy reach of the motorman. It is advisable that one of these switches shall be automatic in action, so as to cut out at any predetermined load.

Both switches should be preferably fitted with an arc-breaking device, and they should certainly be able to break without damage any current likely to be passed through them. We illustrate an automatic circuit-breaker with metallic-shield solenoid blow-out in fig. 1187.

It is not a necessity, where an automatic circuit-breaker is employed, to have a main fuse in circuit, but it is certainly an additional safeguard, and is recommended. The fuse inserted should be of sufficient capacity, so that it will not blow unless the circuit-breaker has by any chance got out of order.

The car cabling, connecting the motors, resistances, and controllers together, should be made up in one or more bundles, having taps made

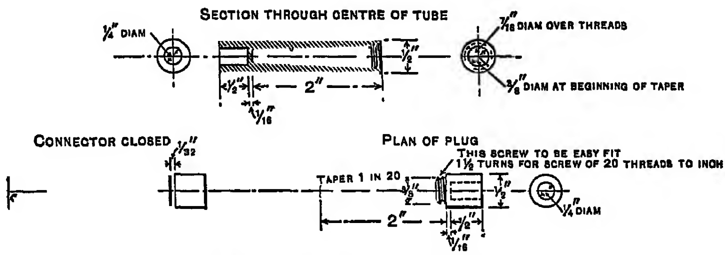

Fig 1188 —Patent Screw-Cone Connector

at the most convenient positions for connection to the motors, &c. The joints must be carefully made, and well insulated The cabling, if not made up in multi-core cable, as is the practice of Dick, Kerr, and Co, Ltd, of Preston, should be enclosed in stout hosing, and should be bound up at the exit of the taps and ends with stout tape, and treated with water-resisting compound. In fixing the cables in the cars they should be run when possible under the longitudinal seats, held against the car sides by leather slings; they should not be placed on the car floor, as this interferes with the sweeping out of the car, and collects the dirt and dust. At the end of the car body they should pass through the flooring and travel along the end-sills till opposite the bottom of the controller, and then be run along a platform-bearer to the hole provided for leading them into the controller.

Some engineers favour the idea of using junction-boxes for the connections between the cabling taps and the motor taps. The ordinary four-screw connector answers the purpose quite well when carefully insulated with rubber and friction tape.

An ingenious connector which has proved of great practical value is illustrated in fig. 1188, and is known as the screw-cone connector. It ensures good electrical contact, is easy to fasten and unfasten; it has no metal screws projecting, which sometimes cause trouble by chafing through the insulation.

Lightning-arresters should be provided on all trolley-cars; but in the case of conduits or surface-contacts and storage systems they are unnecessary. They should be capable of dealing with repeated discharges without attention or readjustment.

Amongst a large number of arresters giving satisfactory results, we may mention the Garton type as possibly being one of the most popular (see fig. 972).

The choking coils, which resist the passage of all oscillatory discharges, should be mounted in series with the car trolley-conductor, and the arrester should be connected on the trolley side of the coil, the other terminal being electrically connected to the rail or earth connection.

CHAPTER III

BRAKES AND BRAKING

The question of brakes is certainly a most important one, and should be regarded by engineers as of quite equal moment to the means of propulsion Far better is it that the propelling power should fail and the car be stuck on the road, from which unenviable position it may be extricated by the next car, than for the braking power to fail and the car to become uncontrollable The writer does not advocate a multiplication of brakes upon a car, a solution of the problem sometimes adopted by engineers who possibly have not practical experience either in handling a car on the road or in the maintenance thereof "Too many brakes spoil the stop" may be taken as an old proverb modernized

It should be the aim of all engineers to have the brakes simple in design, positive and certain in action, and capable of rapid application Each brake on a car should as far as possible be a separate unit, depending in no way upon any other of the brakes, so that if one becomes inoperative it in no way affects the operation of the others.

The Hand Brake.—The ordinary hand brake, worked from either platform by a ratchet handle or hand wheel, is applied to nearly every car constructed. The manner of applying the shoes to the wheels varies more or less with each type of truck, and reference should be made to the illustrations we produce of truck construction. Provision must be made for easily adjusting the wear to the shoes (during service if necessary), and for the automatic equalization of the pressure of each shoe. The shoes should be capable of being removed and new ones fixed on with a minimum of trouble.

A ratchet handle is preferable to a hand-wheel, as taking up less room on the platform, and enabling the brakes to be applied more quickly. If the handle comes to an awkward position it may be pulled back, the spindle being held by the foot-dog provided for that purpose, till it is in a position of greatest convenience for the motorman. The

ratchet is at first a little difficult to work, especially to old horse-car drivers used to a rigid handle, but its advantages are soon appreciated The brake spindle which projects down through the platform floor is attached to the truck levers by a rod and chain, it is advisable that this chain, which winds on the spindle, should be supplemented with another to take up the strain if the working chain breaks. There should always be as little slack on the working chain as possible when the shoes are free, as much time is taken up in winding the slack on the spindle before the shoes come into operation. The leverage of the brake rigging should be such that a man of average strength can effect a total pressure on the whole of the brake-blocks of 100 per cent of the weight of the car unloaded It is impossible to lay down a hard-and-fast rule in this respect, as the capabilities of the driver are a leading factor, and with plenty of leverage at his disposal a skilful man should always be able to judge the force required to get a maximum braking effect. It is only inexperienced or careless drivers that allow the car wheels to skid even on the most difficult conditions of rail, once that they have grasped the power at their disposal and the weight of the car To those acquainted with car driving it is very easy to tell when the wheels pick up by the soft gliding motion and loss of retardation, accompanied generally with a slight lateral motion of the platform, especially noticeable on four-wheel cars

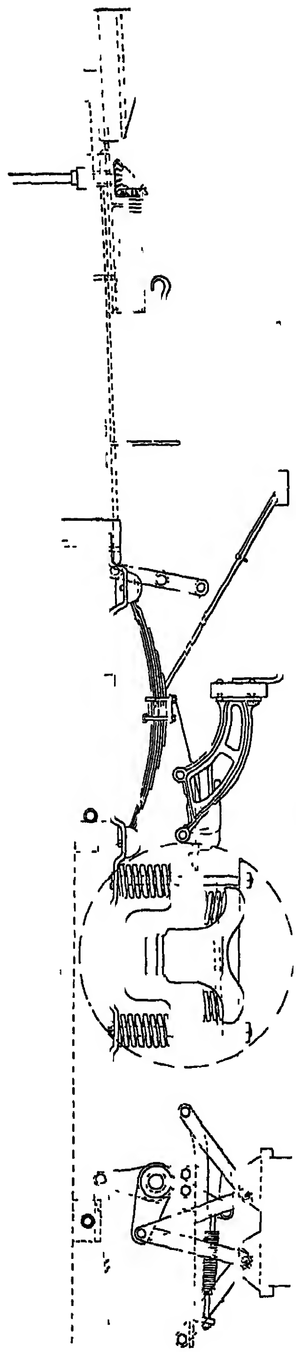

Fig 1189 —Arrangement of Spencer Slipper Brake

Should the wheels develop a small flat from skidding, it is very apparent that this fault will soon magnify itself owing to the tendency to skid at the same place again each time that the brake is applied at all hard. It is quite possible for a painstaking motorman to get rid of a small flat by sawing the brake handle backwards and forwards when running downhill.

When the wheels pick up, the brake should be partially released to allow the wheels to revolve, and a liberal supply of sand applied to the rails, and

then the brakes again tightened up a little, the object being to get as near the skidding point as possible without actually allowing the wheels to stop revolving; this is the point of maximum braking effect.

Slipper Brake.—In addition to the hand brake it is imperative to have another means of retardation. In cases where there are few hills to be negotiated, and none of them severe, it is sufficient to provide an electrical emergency brake hereafter described. Under ordinary circumstances the hand brake should be sufficient to control the car, and the auxiliary brake may be considered merely as a stand-by. Where there are long and dangerous hills, however, it is advisable to adopt also some form of track brake or slipper brake acting by direct pressure on the rails. The ordinary hand-worked slipper brake entirely fulfils the purpose for which it is required, namely, for retarding the car down steep or long gradients. It is usually operated by a hand wheel mounted on each platform, either concentric with the hand-brake spindle or beside it Sometimes a lever instead of a wheel is employed, giving the advantage of more rapid application, but taking up more room on the platform Fig 1189 shows the arrangement of a Spencer slipper brake, a type which has deservedly become very popular. In operation the brake should be screwed on at the top of the hill until the speed of the car is well in hand The hand brake can be used at the same time to regulate the speed, as being more convenient than regulating on the slipper. The shoes are of wood, and easily renewable, the nature of the wood employed varies with the ideas and experience of different engineers to a large extent, beech may be employed with satisfactory results. In considering slipper brakes generally it must always be borne in mind that the greater the pressure between the rail and the shoes, the less weight there is on the wheels, and the more easily are they skidded.

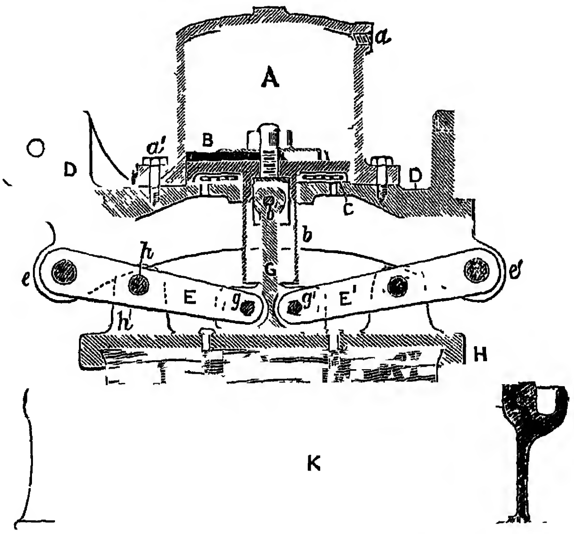

Fig 1190—Hewitt & Rhodes Slipper Brake

Pneumatic Slipper Brake.—An ingenious combination of the air brake and the slipper brake, known as the Hewitt & Rhodes brake, is illustrated in fig. 1190. The advantages of this claimed over the hand-worked brake are. (*a*) instantaneous application and release; (*b*) cushioning effect of the air upon the slippers; (*c*) saving of labour and fatigue to the driver; (*d*) positive and sure action; (*e*) small number of work-

ing parts. The shoes are pressed on to the rails by direct air pressure, the release being made by means of springs which lift the shoes from the rail when the air pressure is reduced. It is not so apparent where the reduction of working parts comes in, but we may consider the air compressor as merely a convenience, and not as a part of the brake itself, which could be, and is, worked quite satisfactorily on the air-storage system. Both for bogie and four-wheel cars it is arranged that there are four separate shoes, two acting on each rail.

The Electromagnetic Slipper Brake.—We illustrate this brake in fig. 1191 as involving quite a novel feature in brake design. The facility with which this brake may be attached to any standard truck

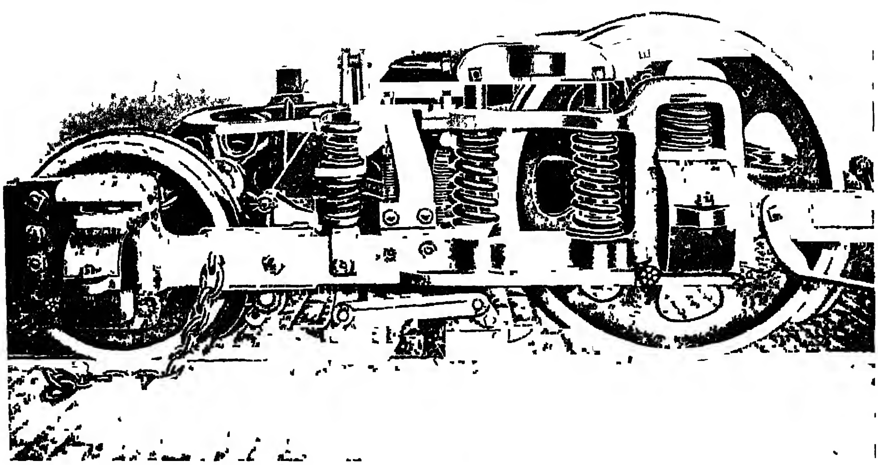

Fig 1191 —Electromagnetic Brake attached to Brill Maximum Traction Truck

will be clear from the illustration In action it derives its power from the car motors acting as generators, which are made to rotate by the momentum of the car, using the energy thus obtained for exciting the magnets operating the track and the wheels' shoes There are three sources of braking involved, namely. (*a*) the adhesion of the slippers to the rail, (*b*) the pressure of the brake shoes on the wheels; (*c*) the retarding effect on the car axles by the load on the motors.

If the brake is to be applied by the controller the latter must be of the rheostatic brake type; a separate brake controller may be employed in some instances, and the effect in any case is regulated entirely by the amount of the resistance placed in circuit on the different notches The higher the speed of the car at the moment of applying the brake, the greater will be the braking effect produced. The brake depending on the motors for its source of energy will, the moment the motors cease generating (when the car stops), become inoperative, and consequently this brake will not hold a car at rest on an incline for more

than a few seconds. However, the slightest motion of the car again applies the brake just as soon as the motors have developed sufficient E.M.F. for re-energizing the magnets. With this type of slipper brake the pressure of the slippers on the rail is entirely an internal force, and does not diminish the weight on the car wheels necessary for the proper operation of the wheel brake. So far those now in service have hardly been running long enough to establish evidence of their economy as a factor of the equipment of a tramway car to justify their general adoption. The brake has much to recommend it, and its operation where already adopted should be watched with great interest. One feature of the brake which must not be overlooked is the fact that in its present form it depends entirely upon other units of the car electrical equipment, namely, the motors, controllers, resistances, and car wiring, and a mishap to any of these may render the brake absolutely useless. This and other considerations, equally applicable to the ordinary rheostatic brake, must be taken account of when debating the type of brakes to be adopted. We deal, therefore, further with this matter under the heading of the rheostatic brake.

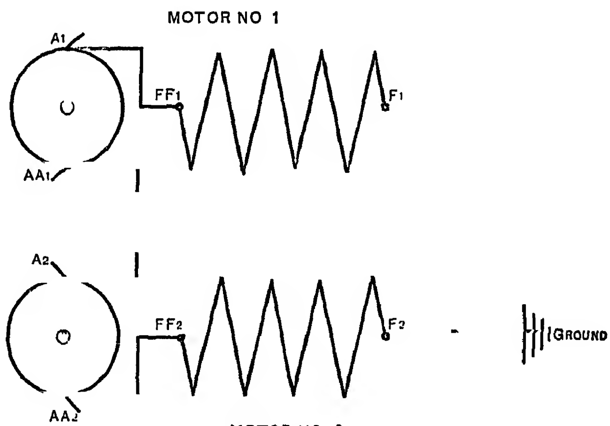

Fig 1192

Electrical Emergency Brake.—In America a large number of the controllers were at one time equipped merely for driving the car, and no retarding device of any kind, short of absolutely reversing the motors, was applied. However, in later years electrical brakes have become more popular, and in Great Britain it is quite the exception to see a controller not adapted for electrical braking. The emergency brake, as its name implies, is only adapted for use in cases of emergency, the stop produced is very severe on the car, equipment, and passengers. The brake is put into operation by shutting off the controlling handle, and pulling the small reversing handle on to the emergency notch, marked on the controller cover, taking care that the handle always passes through the "off" position. That is, if the car is moving forwards the handle must be pulled to its utmost extent towards the motorman, and if the car be travelling backwards the handle must be pushed away from the driver. Fig. 1192 shows the connections of this brake diagrammatically. The forward or backward position of the reverse handle (according to the direction of motion of the car) merely crosses over the armature connections, so that the induced current in the armature

may flow round the field windings in a direction to assist the residual magnetism of the poles, and thus build up the E.M.F. of the motors. The product of the E.M.F. and the resultant current flowing round the circuits being practically the watts absorbed in braking the car. By the very nature of the device the braking effect upon the wheels is proportional to the speed of the car, and if on a greasy track the wheels skid, the brake at once releases for the moment, a result highly desirable, as with a resumption of rotation the brake is again brought into action. Owing to there being no external resistance in circuit the motors quickly attain their maximum E.M.F. for the speed they are running. The brake must never be released until the car has come to rest, as there is no provision for blowing out the arc caused by breaking the current which is flowing. The brake should be applied with the wheel brakes free, and as the car comes nearly to rest the hand brake should be screwed on to hold the car at rest, and the emergency brake then released From the diagram produced it is entirely evident that this brake is quite independent of the trolley-wire current No brake which is dependent upon the trolley-wire current can be of the slightest practical use

Rheostatic Electrical Brake.—This type has found much favour with the tramways in this country, and for general utility and convenience it is highly attractive. In principle it is identical with the emergency brake just described, but is operated by the driving handle of the controller, and not the reversing handle, and is provided with graduating notches, similar to the driving notches, for regulation The brake is applied by swinging the driving handle to the "off" position, and continuing the motion on to the brake notches. There are usually four or more brake notches, each representing a certain amount of external resistance for regulating the effect as desired; an arc-breaking device is provided, so that the brake may be taken off or adjusted from notch to notch without damage to the contacts. Should a car be standing on an up-grade and the hand brake fail, the electric brake may be employed to stop the backward motion by bringing the driving handle to the "off" position and pulling over the reversing handle, as if driving the car backwards, and then operating the driving handle on the brake notches. Pulling over the reversing handle makes the change of connections to the armature leads rendered necessary by the reversal of the direction of the armature rotation This brake, like the electromagnetic slipper brake, and in common with all other electric brakes relying on the motors for energy, is dependent upon the electrical equipment being in good order With the emergency electrical brake there is always less likelihood of the motors failing to build up, as there is in that case no external resistance in circuit. There is no doubt but that the rheostatic brake is a very useful adjunct to an electrical equipment; whether it should be relied upon entirely in the event of failure of the hand brake is open to question in cases of exceptionally difficult tramway routes. The writer is inclined to favour a brake less intimately connected with the rest of the car equipment, *i.e.* an entirely separate unit, such as the hand or pneumatic slipper brake, or the ordinary direct

system of air brake. The rheostatic brake may be applied to an equipment at an almost nominal cost, and the extra working parts involved are negligible It must not be overlooked, however, that in adopting any electrical brake for general service purposes one is asking of the motors a dual duty, and consequently this must assuredly be taken into account when calculating the required capacity of the motors. The rating of a tramway motor is essentially based upon working under intermittent loads, and it is during the periods of coasting on the level

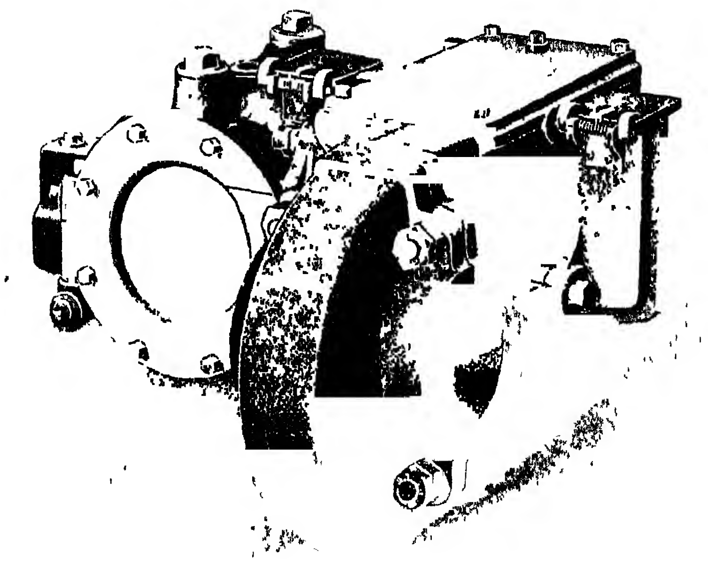

Fig 1193 —Westinghouse Brake Co 's Geared Compressor

and down hills that a considerable amount of the heat is got rid of The mechanical parts of the motor are also subjected to severer strains, increasing more especially the wear to the gears, pinions, and bearings, but it is true at the same time a certain saving is made to the wear of the brake blocks and wheels.

Air Brakes.—Air brakes for tramway purposes are nearly all worked upon the "straight" air system, as distinctive from the "automatic" air systems employing a triple valve as used on the railways, where the length of the train and necessity for instantaneous application upon all the coaches at once renders the straight air system unsatisfactory. The straight air system will operate one or two trailer cars quite successfully. The brakes are generally made to act upon the same blocks as the hand brake, and in

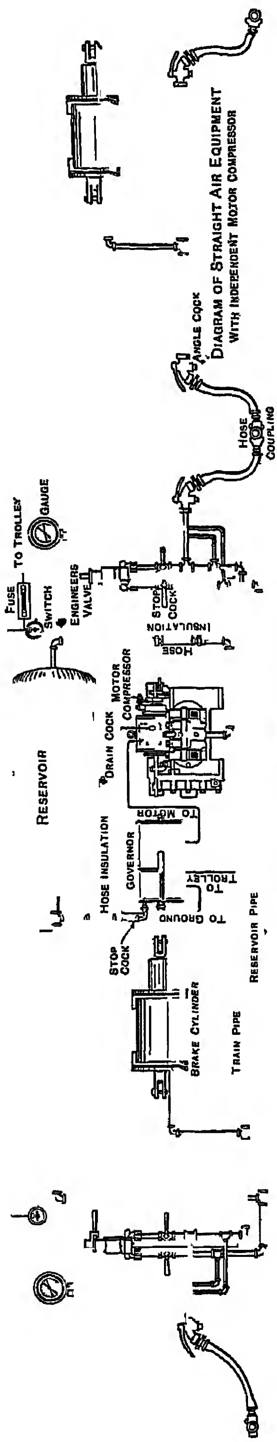

Fig 1194 —Christensen Air-Brake Equipment

order to provide for the free operation of the hand brake, the brake cylinder is so designed that when using the hand brake the piston is not moved along the cylinder; this is managed by making the piston-rod end abut into a cup-shaped cavity in the piston, to which it is not actually attached. The cylinder is single-ended, and the piston is returned to the head of the cylinder upon release of the compressed air by a suitable spring.

The systems usually employed upon tramway-cars may be divided into three headings, as follows. (*a*) axle-driven compressors; (*b*) motor-driven compressors, (*c*) storage A short description of the leading features of each may be of interest. (*a*) The compressors are either of the geared type (see fig. 1193), or are eccentric-driven; in each case they derive their power from the car axle, and deliver the air into suitable reservoirs provided for the purpose. The compressors are specially designed to allow of their being attached to the axle in the space left between the motor axle bearing and the wheel hub The compressors should be furnished with automatic control, so that they will cut out of, and into, operation at any predetermined maximum and minimum pressure in the reservoir. The reservoirs should be fitted with a safety-valve of sufficient capacity to deal with the air should the compressor cut-out fail to act. It should also be fitted with a drain-cock to draw off the water condensed from the atmosphere The air from the reservoir is passed straight to the brake cylinder through the operating or service valve, one of these being situated at each end of the car, the exhaust from the cylinder being sometimes passed through a muffler. On certain types of compressors the exhaust air is made to lift the compressor valves, and so for the first few yards at starting up relieve the motors from extra duty. Whatever type of compressor is adopted, it must be quite dust-proof and self-lubricating, and absolutely automatic in action, its position on the car necessitating the first two conditions, and the latter being essential for street tramway work, where all the motorman's attention is required to pilot his car in safety

through the traffic (*b*) For large cars, and in cases where there is no room on the car axle, a motor-driven compressor is used The motors are, of course, built for the 500-volt tramway circuit. An automatic switch controls the operation of the motor compressor, so that the reservoir pressure may be kept nearly constant, this switch should be capable of being operated by hand if required Fig. 1194 shows the general arrangement of a Christensen motor-driven air brake. (*c*) The storage system, as the name implies, requires sufficient reservoir capacity for making the necessary number of stops between the stations where the reservoirs may be replenished The system shows to best advantage where the stops are scheduled and intermediate stops infrequent.

Air brakes in general are an expensive item of a car equipment, and the advantage of their adoption on small cars running without trailers is questionable. They apply the shoes more quickly than does the hand

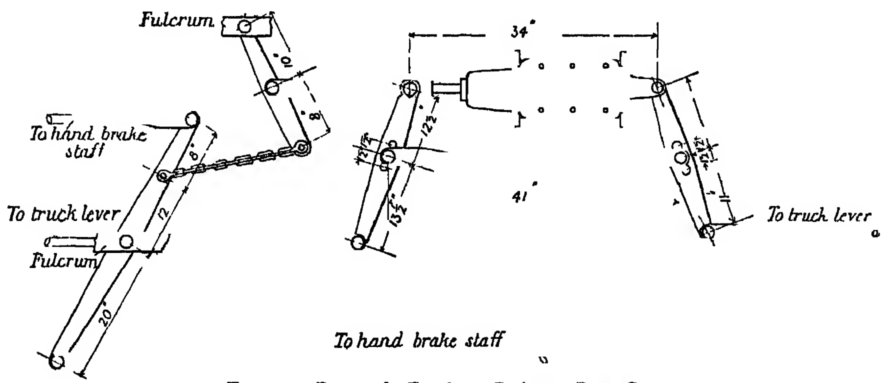

Fig 1195 —Rigging for Equalizing Brakes on Bogie Cars

brake, and for heavy cars they undoubtedly are of great benefit In cases where trailers are in general use they offer advantages over braking by hand, as by the simple attachment of a hose-pipe and coupling at each end of the cars and trailers, and the addition of a brake cylinder to each trailer, the brakes of the whole train of two or more cars may be controlled from the front platform When trailers are used additional reservoir and compressor capacity must be provided, and in calculating the amount of air used for each application it must be taken into consideration that the pipe connections from the service valve to the cylinders are for each application filled with live air, and are exhausted with the cylinders on the brakes being released Pressures of over 50 lbs. per square inch are unusual, but when met with are generally obtained by compressing in two stages, and compound compressors are built for this purpose

Fig. 1195 shows a very efficient style of brake rigging employed by the Westinghouse Brake Company for use on double-truck cars, ensuring the equalization of the braking power on both trucks.

Electric Disc Brake.—This is a brake that is not very largely in use in this country. In principle it depends, in the first instance, on the motors being run as generators, as in the case of the rheostatic brake, &c. There

are on each of the car axles two iron discs, the one keyed tight on and revolving with the axle, and the other fixed in close proximity and energized by coils in series with the motors. There is, therefore, the retardation due to the artificial load on the motors, and also the mechanical friction between the two faces of the discs, one of which is so arranged that it is free to advance by magnetic attraction towards the face of the revolving disc. There is also a further braking effect due to the eddy currents set up in the revolving disc.

We have mentioned above a few of the best-known types, there are many others that might be mentioned in a larger work on this very important detail of car equipment.

Sanding Arrangements.—With self-propelled vehicles the question of sanding the rails assumes a far more important aspect than in the case of horse cars, where a box of wet sand is hung on the dash to be strewn on the track by hand when required. It has been recognized that dry sand fulfils its purpose better than wet, as it tends not only to give a grip owing to its gritty nature, but also dries the track. It would be impossible to scatter dry sand in the old way, as it would be blown away, and therefore proper sand-hoppers are fitted to the cars with the delivery-pipes leading right down to the rail head. The sand used should be sharp and gritty, and before being placed in the car hoppers should be thoroughly dried, for which special ovens are generally constructed in the car depot. When the sand is derived from the sea-shore it is sometimes necessary to wash out the salt, as even after baking, in damp weather, it will absorb moisture and clog the sand valves. We instance two well-known types of sanding gear the Ham, representing an intermittent-flow type; and the Common-Sense, the continuous-flow type The hoppers are worked from the platform by the motorman's right foot pressing on a plunger. With the continuous type, as long as the plunger is depressed the sand will flow, thus it has the advantage of giving an even distribution of sand along the rail, but there is always the danger of the valve becoming stuck by a small pebble getting in the way of it closing, and allowing the sand to slowly escape unknown to the motorman In the case of the intermittent type the motorman presses and releases the plunger alternately; this pumps the sand on to the rail with fairly even distribution. It is now becoming quite general to place four hoppers on each car, and so sand both rails. The older and more usual practice was only to sand the off-side rail, leaving the other clean for the necessary electrical contact. It is advisable, if four hoppers are to be employed, for the off-side and near-side boxes to be worked by separate pedals, placed near enough together so that the motorman can cover both with his one foot if necessary. Sanding both rails when going uphill, unless absolutely necessary, should be avoided, as it renders the current through the motors more or less intermittent. When passing over any points and crossings sand should never be let fall, or the former will very soon become clogged and cause trouble. In greasy weather a motorman should continue sanding the rail till the actual moment the car comes to rest. By so doing he has the rail sanded in front of his wheels for a good start; it often takes a lot of trouble to get a car from the position of the

wheels at the stop to the point on the rail below the sand delivery-pipe On large cars where air brakes are used, sand is sometimes served to the rail by means of an air blast; the practice is, however, exceptional.

CHAPTER IV

CAR TRUCKS, ETC.

The car trucks for electric-traction purposes must be designed not only to carry the car body and to give it an easy riding motion, but must also provide for the suspension of the motors in such a manner that they are subjected to a minimum of vibration. The tractive effort exerted

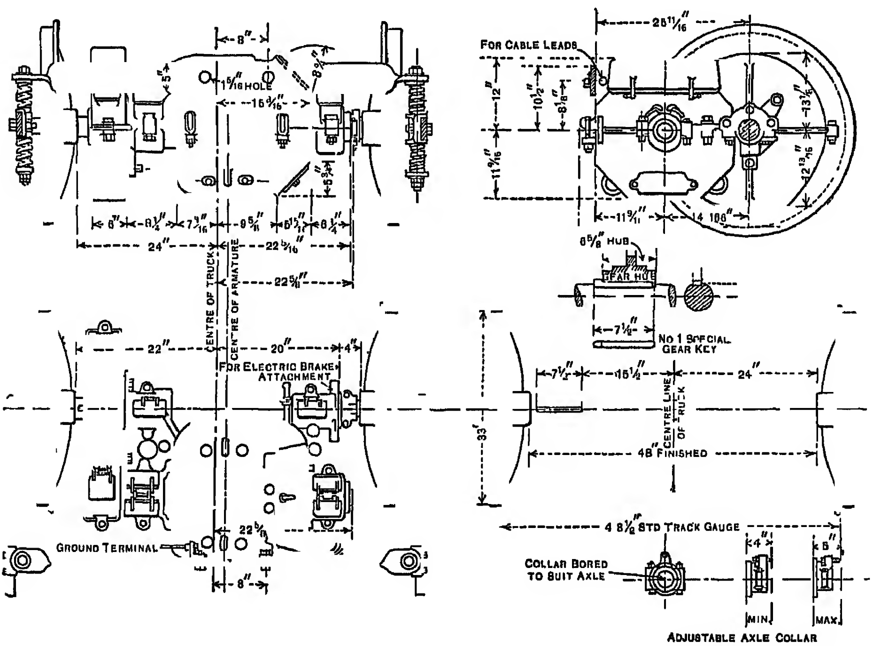

Fig. 1196

by the motors is transmitted from the car axles to the axle-boxes, and from these to the truck side frames The side frames are separated from the top bars by a system of springs, and it is through these springs that motion is imparted to the car body, which in the case of single-truck cars is bolted to the truck top bar. It will be seen, therefore, that the springs must not only ensure the easy riding of the body, but must withstand the horizontal strains of rapid acceleration and retardation without undue pitching.

The most usual method of suspending the motors is by carrying a large percentage of the weight of the motor direct on the car axle

through the motor axle bearings, the back end of the motor being provided with a bracket or other means of attachment to a cross-bar supported on the truck side frames entirely on springs. This method is shown in fig. 1196, and is known as the "Nose" suspension. A method sometimes employed is the "Side-Bar" suspension, in which case the motor is upheld by two bars, one on each side, running parallel to the truck side frames, and ultimately attached to them by means of springs. In this case support is given to the motor at a point nearly in a perpendicular line with the centre of gravity of the motor, and consequently the axles are relieved of a large proportion of their direct weight. This suspension is not, however, in general use, though it has been introduced for some very considerable time, and has not been without trial by any means.

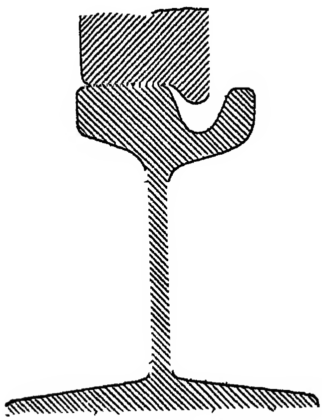

Fig 1197 —Section of Wheel and Rail for Liverpool

Trucks may be divided primarily into two distinctive classes, namely, the rigid four-wheel truck, and the bogie or swivelling truck. The latter class may be again subdivided into maximum-traction and equal-traction types

It is only to be expected that the primary consideration in determining the class of truck to be adopted is the type and length of car body. Other considerations, however, have an important influence on this subject, such as the loads, curves, gradients, speeds, &c

Rigid Four-Wheel Trucks. — This type, owing to the popularity of the short double-deck car, is considerably in the majority, and is suitable for carrying such car bodies up to about 20 feet or more with easy riding, though the majority of trucks are carrying cars of 15 feet 6 inches to 16 feet 6 inches over the corner posts, in which case the wheel base, or distance between the axle centres, is not necessarily more than 6 feet. Wheel bases most commonly met with are 5 feet 6 inches and 6 feet, and in some special cases 5 feet, 6 feet 6 inches, or 7 feet are adopted It is advisable to keep the wheel base as long as can be comfortably worked with the curves to be rounded. It is evident that the longer the wheel base, the greater will be the difficulty in rounding curves. It may be taken that a 6-foot wheel base will round with comfort a curve of 35 feet radius, and can even be run on shorter curves than this if it is found necessary. No hard-and-fast rule can be laid down, as a great deal depends upon the section of the rail employed and the profile of the car wheels

The trucks should be cross-braced in such a manner that when rounding curves or taking points they are able to withstand the consequent strains without racking the car underframing. Where it is possible for the track to be laid with transition curves, the strains both on the truck and body are very considerably reduced, and the curves may be taken with safety at a much higher speed. In rounding curves there is bound to be a certain

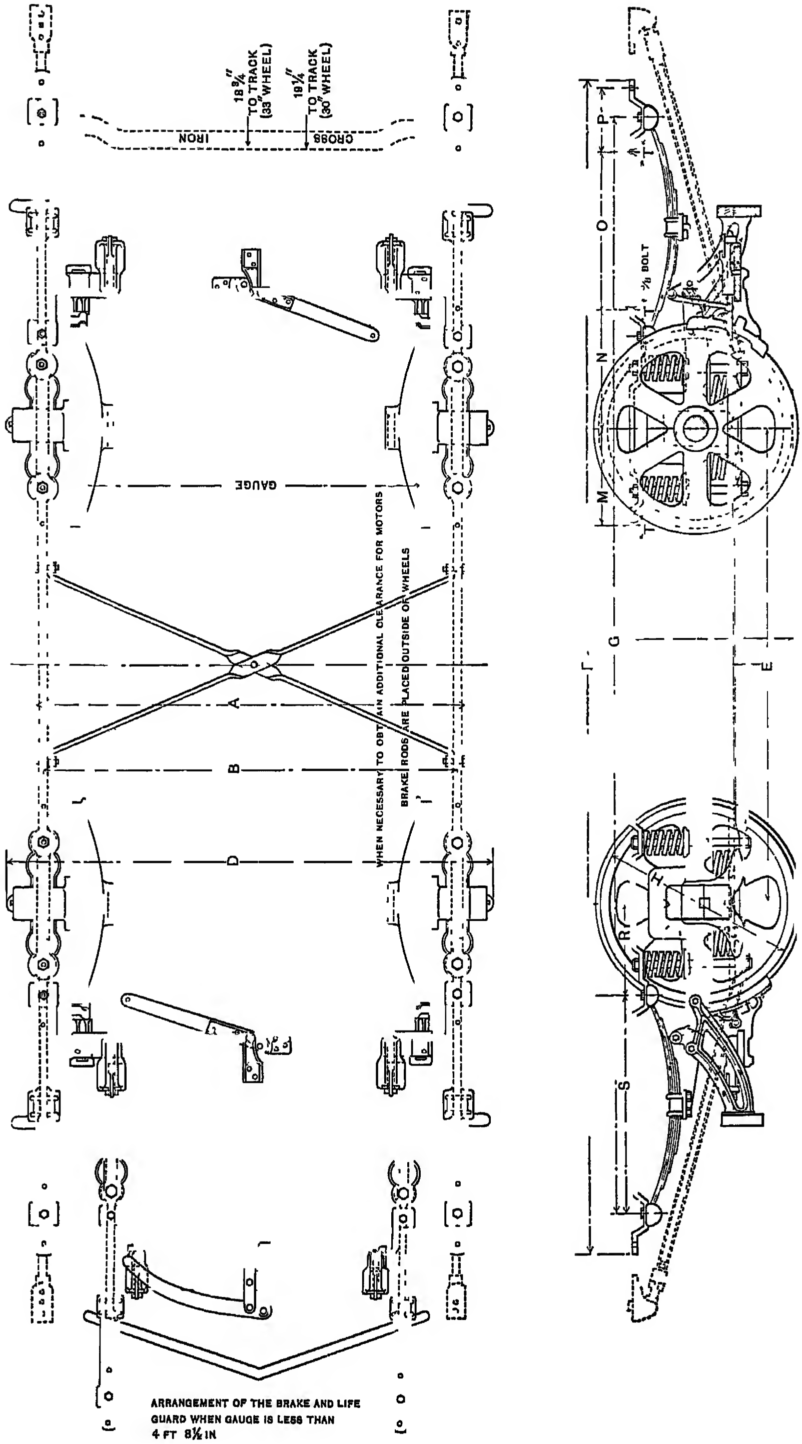

Fig 1108 —Standard Bull Truck

grinding action between the wheels and rails, but this is somewhat diminished by the centrifugal action of the car tending to throw it off at a tangent to the curve, thus pressing the flanges of the outside wheels against the rail, and so, the diameter of the wheels at the root of the flange being greater than at the outside edge, this has a slight compensating effect towards making up the greater distance they have to travel. Fig. 1197 shows the profile of tread and flange of the wheels on the Liverpool Corporation tramways in relation to the rail employed.

We illustrate in fig. 1198 a standard Brill No. 21 E single truck. It will be noticed that the side frames are of one piece, this being a speciality of this particular make, and the manufacturers claim for this construction immunity from depreciation due to the incessant strains and blows, which in a built-up side frame have to be withstood by the bolts and

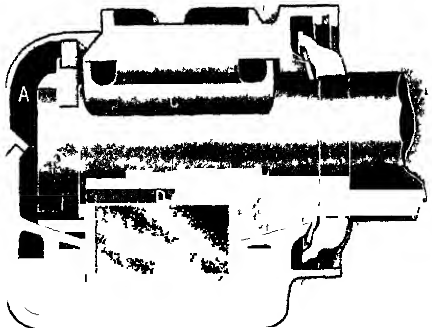

Fig 1199—Section of Brill Axle-Box

rivets, &c, holding the members together Extension rods are provided with this truck for use with extra long car bodies We reproduce an illustration (fig 1199) of the Brill axle-box in section, this box may be used either for grease lubrication or for oil, with equal facility It is necessary that the journals shall be self-lubricating, and shall require no attention other than the periodical refilling and occasional inspection The box is provided with a cover easily removable from the outside, and the check plate, or thrust collar, and the saddle brass may be removed for examination by relieving the pressure of the car weight by means of a small jack inserted under the truck frame. The outside of the axle-box casting is provided with two wings on either side of the base on to which the truck side frames rest supported on spiral springs The axle-boxes should fit into the horn plates of the side frame with plenty of clearance, and the boxes should be free to ride up and down the horn plates.

The connection in the Brill 21 E truck between the side frames and the top plates are made by four spiral springs and two semi-elliptical springs each side of the truck, the elliptical springs being placed at the

extremities of the spring base, their function being to steady the action of the spiral springs, which otherwise would allow the car to get up a rhythmic pitching or oscillatory motion.

The Peckham four-wheeled truck is an example of the built-up side-frame class, and has met with considerable appreciation. The construction is on the cantilever principle, and to follow this out it is necessary that the horn plates have filling pieces made to fit tightly in under the axle-boxes, and to remove these, for rewheeling the car, it is necessary to spring open the horn plates slightly. In the Peckham truck the weight of the car and truck side frames is taken on the top of the axle-boxes, springs intervening The two trucks we have mentioned above both emanate from the United States of America. It is now, however, possible to purchase trucks manufactured in Great Britain, and amongst others who have entered into this industry may be mentioned the Brush Electrical Engineering Company. By far the greatest number of trucks now running, however, are of American manufacture, and we are led to believe that so far as numbers go the Brill Company hold considerable lead

Maximum-Traction Bogie Trucks.—We will first deal with that class of bogie truck known as the maximum-traction truck These trucks are designed for use where circumstances will not permit of the use of rigid four-wheel trucks, and where two motors only are required on each car The use of double trucks, in general with their short wheel base, this being usually only 4 feet, greatly facilitates the rounding of curves which could not safely be negotiated with single trucks and longer wheel bases. Generally speaking the driving-wheels are 30 inches or 33 inches in diameter, while the pony or trailing wheels are 20 inches in diameter

It is obvious that if a car mounted upon eight wheels, each of which is taking an equal share of its weight, is only driven on four of the wheels (*i e* two axles), that the weight for traction obtained will only be half of that had the car been mounted on a four-wheel truck, this is of course eliminating any consideration of that portion of the weight of the motors which comes direct on the driving-axles. Consequently it is perfectly clear that an equal-traction bogie car, unless provided with four motors, one on each axle, is not desirable The writer has observed in Newcastle-on-Tyne on such cars, where equal-traction bogie trucks driven only on two axles were employed, great difficulty in greasy weather of surmounting even the most moderate grades, and the question of equipping the cars with four motors was seriously under consideration Another proposition was put forward at the time, namely, that the idle-wheels should be geared to the driving-wheels by some mechanical device Similar experience was obtained in Glasgow with equal-wheeled bogies, driven only on two of the axles

The arrangement of the maximum-traction truck allows of 75 per cent to 80 per cent of the car weight coming on to the driving-wheels, to which must be added a greater portion of the weight of the motors, so that only from 20 per cent to 25 per cent of the weight of the car, and a small portion of the weight of the motors, is lost for traction purposes. This small amount is that which is necessary to compel the pony-wheels to keep the track. This device is a considerable improvement upon equal-traction

trucks, but it must never be expected that a maximum-traction truck car will mount steep grades, and descend with the same amount of safety and ease as a four-wheel truck which employs every ounce of its weight as useful traction. Where large cars are to be worked, and steep grades are met with, there is no doubt a four-motor car is advisable.

As only a small portion of the total weight comes on the pony-wheels of a maximum-traction truck, it is necessary that the wheel-brake pressure is divided in the same proportion, or else the pony-wheels would skid before the full braking effect was reached on the driving-wheels We illustrate in fig 1200 a Brill "Eureka" maximum-traction truck, and it will be seen, to gain this end the pressure on the pony-wheel shoes is transmitted through adjustable springs.

Bogie trucks generally, unlike the four-wheel rigid truck, are not bolted to the car body in any way, but the body rests on two rub-plates, one on each side of the truck In the case of the Brill maximum-traction type the rub-plates are supported from the truck side frame by two spiral springs and spring posts, and fit into corresponding angle plates of the same radius attached to the car body, and all these are concentric to the pivotal point of the truck, which is located about 6 inches from the central point of the driving axle in the direction of the pony axle. The thrust of the truck on the car body is taken on a king-pin attached to the car framing, which projects through a suitable motion block running in a radial slide, as shown in the illustration. The truck is also furnished with a compression device consisting of a plunger supported by a heavy spiral spring, which latter is capable of adjustment; the plunger, pressing upwards, bears on a metal plate affixed to the car underframing, shaped so that the compression is least when the car is on the straight track. It is by this compression device that the percentage of weight upon the pony-wheels may be varied to a considerable extent by adjustment. The illustration we produce shows this compression device separately in section

The brake-rods, in the case of trucks for 3-feet-6-inches and 4-feet gauge, are placed outside the wheels, this also being the case with single-truck cars, and in special instances on the standard 4-feet-8½-inch-gauge trucks where rendered necessary for clearance required for air-brake compressors or other auxiliary gear

The brakes on the two trucks are connected to a cross-beam attached to the underframing of the car, to the extremities of which are attached the pull-rods and chains connected to the brake spindles on the platforms. By means of short chain connections and pulleys it is arranged that the braking pull on each truck is equalized from the cross-bar. In order to provide for the swing of the truck on curves, the connection between the cross-bar and each truck brake rigging is made by radial yokes, and the pull-rod ends are provided with small friction-wheels running in the yokes. This ensures that the brakes are not dragged on when the car rounds any curves, which otherwise would be the case, this is clearly shown in the illustration. As seen from the same illustration the motor is to be located between the two axles, the arrangement of suspension being almost identical with four-wheel single trucks.

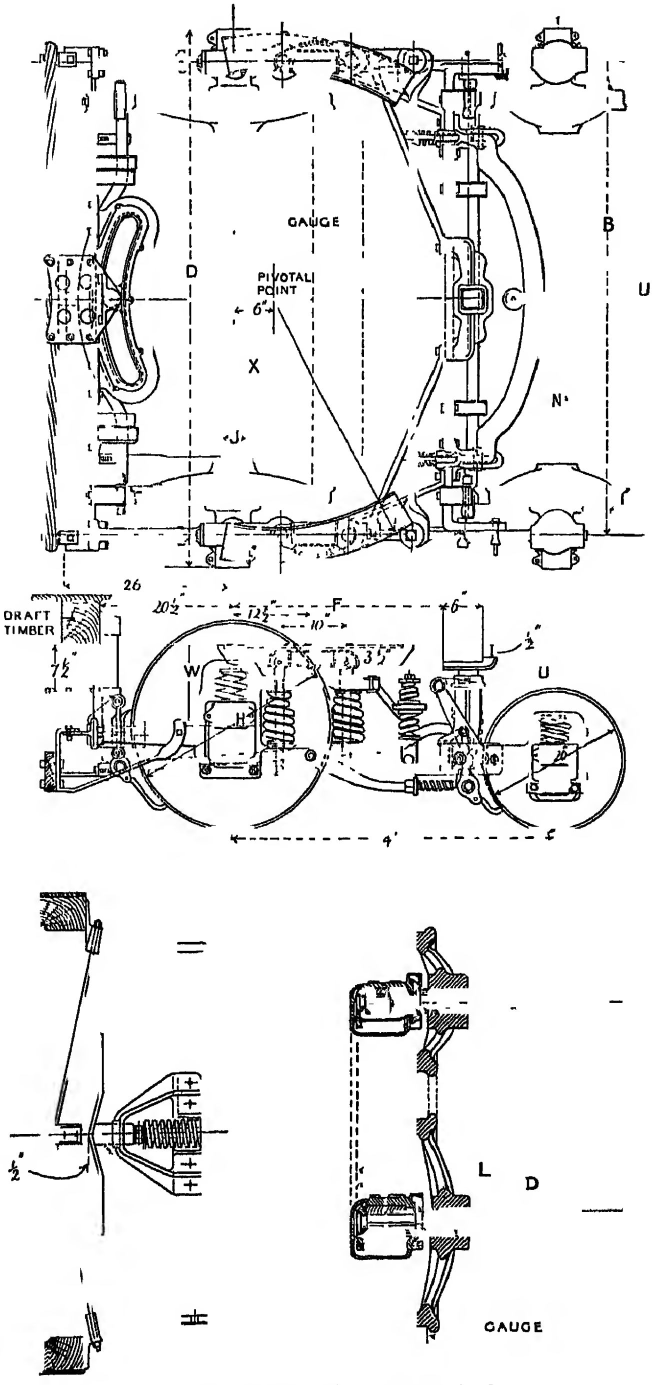

Fig. 1200.—Brill Maximum-Traction Truck

Equal-Traction Bogie Trucks are specially adapted for heavy long cars, where the conditions of service demand the extra horse-power obtained from four motors, or where the gradients prohibit the use of maximum-traction trucks The traction is the maximum obtainable, owing to every wheel being a driving-wheel and bearing an equal share of the weight, and therefore can be classified in this respect with the four-wheel single truck. The use of four motors increases the acceleration of the cars, and consequently the average speed, besides decreasing the losses from poor wheel adhesion. We have only to look at steam locomotive practice to find that for roads on which there are heavy gradients, the locomotives for heavy trains are either four or six wheels coupled in order to obtain the necessary traction

It has been found that with proper methods of control, and suitable motors, quadruple-motor cars compare upon a favourable basis with even the four-wheel single-truck car so far as current consumption and general economy are concerned, and there is a growing tendency on the part of tramway engineers to realize the comparative merits of quadruple-motor cars in comparison with double-motor cars with maximum-traction trucks. In support of this it may be mentioned that the Board of Trade have sanctioned the proposal to equip certain tramway routes with quadruple-equipment cars, which sanction they would not grant even for working double-deck single-truck cars Needless to say, the grades on the tramways we refer to are considerably above the average met with in street car work; but much importance should be attached to this, as many routes hitherto deemed impossible for electric traction may now be sanctioned under similar conditions. Where a mixed system of cars is employed, comprising some single-truck and some bogie cars, the use of quadruple equipments will in most instances enable the heavier bogie cars to be run with the same type of motors as the single-truck cars, thus reducing to a great extent the amount of motor spare parts to be stocked, and at the same time effecting entire interchangeability So far as the special controllers are concerned the spare parts mostly required are cheap, and consist chiefly of contact fingers and segment tips

Like the maximum-traction trucks the usual wheel base is 4 feet, but the motors are hung from the axles towards the truck extremities, and not between the axles

These trucks are constructed not only for ordinary tramway purposes, but for the heavier light railway traffic, where motors of 100 horse-power are sometimes mounted on each axle.

Where the demands of traffic call for a large seating capacity it was customary to run trailer cars attached to the four-wheel motor-cars, but experience has shown that this is false economy, even when dealing with intermittent pressure of traffic, and a very dangerous practice into the bargain. Trailer cars form a source of danger to passengers alighting from the motor-cars when in motion, and in spite of what may be the regulations governing the system, it would be a very serious matter if the train were brought to rest to pick up or drop every passenger carried The practice of adopting definite stopping-places is no doubt advantageous,

but a large percentage of these are run by, passengers preferring to jump off or on at the most convenient spot to themselves. Instead of adopting trailers it is necessary to provide larger cars, and the general tendency is towards the adoption of equal-traction trucks and quadruple equipments. In busy cities the extra demand is usually met by diminishing the headway between the cars by putting more cars on the route, and the reserve of cars on a large system should be sufficient to do this But for long journeys into the suburbs this practice gives place to the adoption of larger cars. It is natural that there should be some hesitation before adopting quadruple-equipment cars, chiefly on account of the largely-increased prime cost of both the trucks and equipments, and the extra cost of power required, it being an undoubted fact that four, say, 20-horse-power motors will not give the commercial efficiency of two 40-horse-power motors on the test bed The question, therefore, resolves itself into the problem as to whether the loss in the working of four-motor cars is greater or less than the cost of purchasing and running extra motor-cars, and supplying their crews only to be used for a few hours each day, besides the extra expenses of shed room, cleaning, and maintenance We are inclined to think that in most instances for suburban work the larger cars will be the most economical in the long run

Wheels and Axles.—Axles for electric cars are usually steel, but in some instances wrought-iron is employed. The steel is usually cold-rolled, cold-drawn, or hammered, the former process is more generally employed The body of the axles is mostly of $3\frac{3}{4}$ or 4 inches diameter, and the truck journals of 3 to $3\frac{1}{2}$ inches diameter It is convenient to mill the gear keyway out before the wheels are pressed into position Where end-thrust plates are not used, about $\frac{1}{2}$ inch from the extremity of each axle journal there is a recess of about $\frac{11}{16}$ inch by $\frac{1}{2}$ inch approximately for the reception of the thrust-plate of horse-shoe shape which slips into guides in the axle-box, and takes up both the forward and lateral thrusts The weight of the car is taken entirely on the axle journals, and a saddle-shaped brass forms the bearing surface In order to prevent dust getting into the axle-box a malleable-iron dust-collar is shrunk on to the axle near the outside boss of the wheel, and between this and the axle-box casting is generally placed a fibre ring For driving axles the general practice is to machine them all over, but trailing or idle axles are only machined over the journals and wheel seats. The wheels are pressed on at a pressure of between 20 and 30 tons, care being taken to get the gauge-point of each wheel equidistant from the centre of the axle. The wheels should be pressed to a proper gauge-bar, sufficient accuracy being observed to ensure that they have not more than $\frac{1}{16}$ inch variation, this being the practical limit allowable in pressing wheels. The wheel gauge should vary from the track gauge by from $\frac{1}{4}$ to $\frac{3}{16}$ inch in order to give the necessary clearances The usual diameter of wheels is from 28 to 33 inches, wheels of 30-inch diameter being the most popular in this country. They are usually made of cast-iron, and in the casting are chilled around the flange to a depth of $\frac{3}{4}$ to $\frac{7}{8}$ inch. After the castings have set they are removed from

the mould, and subjected to an annealing process in order to prevent uneven contraction and consequent internal strains. As a result of the chill the rims are so hard that they cannot be touched even by a file, so that any irregularity must be trimmed up by means of emery grinders Cast-iron chilled wheels are liable to suffer from chipped flanges, more especially where the track-work is bad, or where obstructions get into the rail groove, such as large-headed frost-nails, &c The use of steel-tyred wheels is generally becoming more popular. The wheels are considerably more expensive, but will give a greater car mileage than cast-iron. Again, they do not suffer to such a degree from chipped flanges, and take a better bite of the rail The tyres are generally mounted on wrought-iron or cast-steel centres In the case of disc centres, in order to avoid the ringing sound, these are broken up by several holes being introduced into the disc. The steel tyres are shrunk upon the centres, and are additionally held by set-screws. The centres and tyres are provided with shoulder and recess to ensure their taking up a proper relationship to one another, and also with a view of withstanding the side-thrusts to which they are subjected. A mileage of 20,000 to 50,000 miles according to hardness and size may be expected from tyres which from time to time require turning up in a lathe An ultimate reduction in diameter usually specified is about 1¾ to 2 inches With chilled cast-iron wheels we may expect a life of about 20,000 miles as an average minimum, and a reasonable estimate should be 25,000 to 30,000.

CHAPTER V

CAR FENDERS AND LIFE-GUARDS

For the protection of the public, in recent years considerable attention has been paid to the provision of some device whereby persons falling or being knocked down in front of an electric or mechanically-propelled tram-car may be protected from serious harm. It is not many years since it was considered sufficient to provide the truck with the usual tail-board, these sometimes being shaped like the letter V with the object of pushing the obstacle to one side The Board of Trade, however, of late have given considerable attention to this question, resulting in a large number of life-guards being brought into existence, the majority of which have proved themselves utterly useless for practical life-saving, although they may be made to pick up dummy straw-men in the most approved style. Considerable difficulty has been experienced in selecting life-guards by officials of the various tramway systems, owing to the fact that the different inspectors of the Board of Trade appear to have very different notions as to what is an effective guard In fact, certain guards have been passed as efficient on one system, while at the same time or a few weeks later upon another system they have been condemned Under these circumstances, when choosing the type of fenders for a

system, if it is possible to get an expression from the Board of Trade as to the type they will approve of, it is wiser to follow this course.

We will only include mention of some of the best-known fenders which have, so far as we can tell, met with the Board of Trade approval during recent years

Life-guards may be divided into three classes:—

(*a*) Those which project beyond the car itself
(*b*) Those which are placed under the car platform, but which are without automatic action
(*c*) Those placed under the car platform, and which are automatic in action.

(*a*) Of these guards the best-known is the Providence fender, and in America it has become very popular. It is attached to the front of the car, and projects from there forwards and downwards till a few inches off the ground, forming a scoop in which obstructions may be caught up In order to avoid injury to persons caught up a spring buffer is provided, upon which they are received The fender is constructed mostly of metal strips and rods attached to metal castings, the end of the guard is provided with rollers, so that when coming in contact with the roadway it does not buckle, but rides easily over it The guard can be folded up when not in use

A much similar guard to the above is the Dover life-guard This is somewhat lighter in construction, and consequently cheaper to manufacture In operation it is found to be very efficient, and projects to a less degree than the Providence Its lightness and ease of detachment enable the use of only one per car, but if two are used the one not in use may be folded neatly up

This class of guard is no doubt very efficient, but owing to its projection in front of the car it is not only exposed to greater chances of injury, more especially in crowded traffic, but is sometimes itself the cause of accidents by tripping people up who otherwise would have cleared the car

(*b*) This type is represented by the Peckham life-guard, which till quite recently was almost universally adopted The Board of Trade inspectors have now more or less unanimously condemned this type It therefore suffices to say that it consisted of a horizontal framework filled in with wire-netting forming a kind of tray, the sides of the frames being attached to the truck side frames, and the fender being supported on springs attached to the truck tail-board or the car platform-bearers A wire screen was provided to prevent injury from contact with the tail-board.

(*c*) The best-known fenders of this class are the Wilson & Bennett, the Tideswell, and Hudson Bowring. Speaking generally, they operate on similar principles, and consist of guards placed under the platforms which are lowered either by the motorman or by an object on the track coming into contact with a gate hung from the front portion of the platform. The Wilson & Bennett is constructed chiefly of metal, and is more

expensive and complicated than the Tideswell, besides being of greater weight and strength. In operation these fenders have proved their thorough efficiency. The Tideswell is built of wood laths and wrought and cast iron. The fender is illustrated in fig. 1201.

Owing to their nature and position all fenders are subject to more or less frequent damage, and one must bear this in mind when deciding upon the type to be adopted; obviously the one which most recommends itself from a tramway engineer's point of view is that which costs least for maintenance, and is the most cheaply repaired, and which is least exposed to damage.

A great source of danger from falling under a car is the brake spindle projecting through the platform, and the draw-heads for coupling the cars together. The former cannot well be dispensed with,

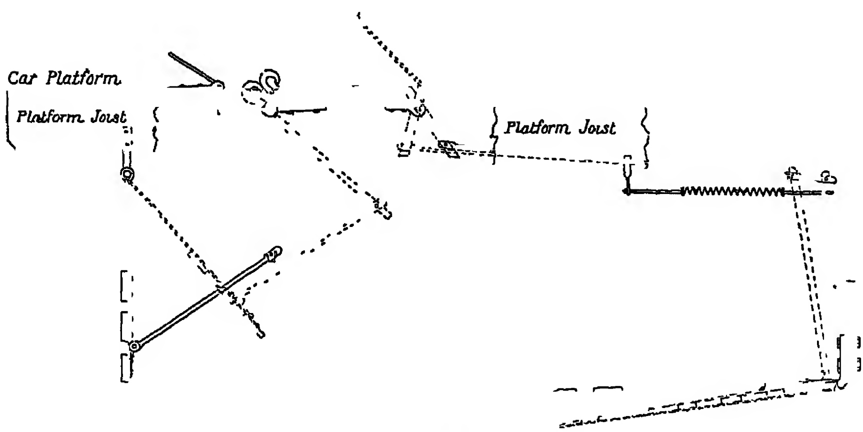

Fig 1201 —Tideswell Life Guard

but in many cases the latter are replaced by draw-pins and short chain or wire cable lengths. Such an arrangement, though unsatisfactory for running trailer cars, is quite adequate for towing disabled cars to the depot, and can be universally adopted where trailers are not employed. The Providence or Dover fenders catch the object and prevent it from getting under the platform, but are found very unsuited for busy streets, for country routes they are most excellent

It is more difficult to protect bogie cars effectually owing to the swing of the trucks, but the same type of fenders are usually employed. With bogie cars it is a wise precaution to guard the open space under the car body between the two trucks with a stiff framework covered with wire-netting, the guard coming down to within a few inches of the rail level. This should be easily removed without getting the car on to the pits.

Before leaving the subject of life-guards we should mention that fenders of the mechanical-gate type are troublesome during snowy weather, owing to the fender being released whenever the snow piles up against the gate. It is, however, seldom in this country that snow

should get ahead of the management of a tramway system, and means are generally taken to keep the road fairly clear for traffic, even if it is necessary in order to keep the line open to run cars all night to prevent an accumulation of snow on the track.

CHAPTER VI

MISCELLANEOUS

There are many attachments more or less extraneous to the actual equipment of car rolling-stock, and to which we must make some slight reference.

Rail-Brushes.—These are extremely useful for keeping the head of the rail clean, and for ensuring good electrical contact. The brush,

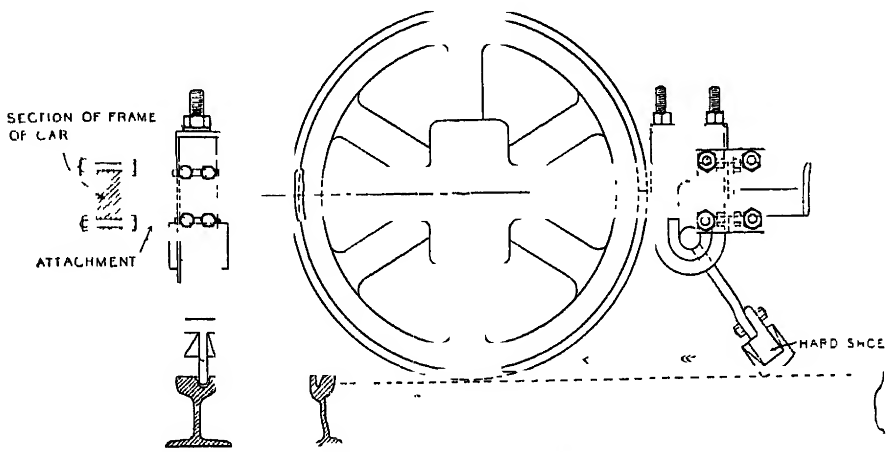

Fig 1202 —Jarrard's Rail Scraper

which is of steel bristles, is held in the brush-holder in such a manner that it can be easily raised or lowered, and the pressure on the rail regulated They are usually attached to the truck side frame

Rail-Scrapers.—These consist of metal shoes which are mounted on holders so arranged that while giving a good pressure on the rail they will adjust themselves to the inequalities of the track, and if they take the wrong points will, without damage, spring of themselves into the proper rail again. The device may be attached either to the car body or truck side frame, the latter is preferable, owing to the less variation of height due to the motion of the truck springs. We illustrate in fig. 1202 Jarrard's patent track scraper as an example The scrapers thoroughly clean out the groove, this being most effectually performed if the rail has previously been watered to soften the dirt.

Some tramways attach a short piece of chain to the car and drag

it in the groove. This certainly helps to keep the groove free, but will not break up and cast aside any caked dirt as will the scrapers designed for this purpose.

Sleet Wheels.—These trolley wheels are only for use during a fall of snow or sleet when the wire gets covered with ice. The groove of the wheel is ribbed, which has the effect of cutting through the thin layer of ice. A good plan, if sleet wheels are not handy, is to choke an ordinary wheel to prevent it turning; this will clean off the ice from the wire in quite a satisfactory manner.

Speed Indicators.—The Board of Trade usually order that these shall be fitted to each car, but this rule is seldom if ever enforced, probably due to the fact that they realized at one time the almost impossibility of procuring a suitable indicator Truly of later days there are indicators of more or less merit to be bought, but as the Board of Trade have allowed this clause to become in the past practically a dead letter, it is natural that engineers do not adopt an apparatus which must add to the maintenance costs and which is of no earthly use from their point of view.

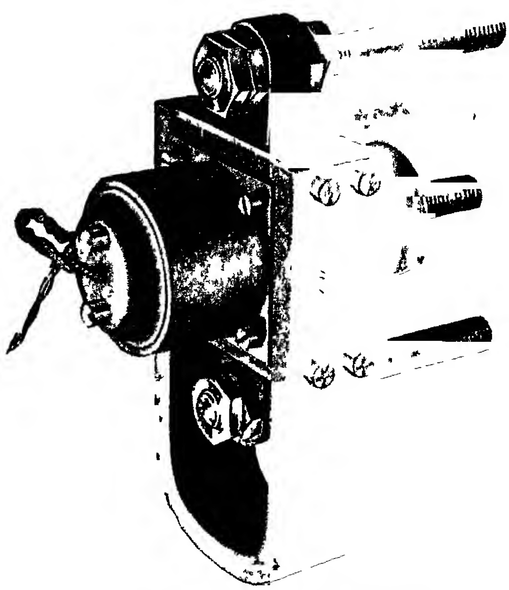

Fig 1203 —Highfield & Beeton Speed Indicator

Some indicators are made to drive off the car axle, and the motion is then transmitted to each platform by means of a flexible coupling, where an instrument is operated giving readings in miles per hour.

One of the most simple and ingenious indicators is the Highfield & Beeton patent. In principle it depends upon the voltage generated by a small permanent-field direct-current generator, coupled on to the end of the motor armature shaft. The magnetic field of the generator is shunted in order to get a field as constant as possible. The whole apparatus is self-contained, and is attached to the motor shell, due allowance in design being made for the wear to the motor armature bearings. The generator is entirely without bearings, is dust-proof, water-proof, and strongly made to withstand rough usage The readings are made on dead-beat voltmeters, one on each platform, calibrated to read in miles per hour. The dial on the driving platform alone indicates the speed, thus passengers are not able to tell the speed of the car, the instrument on the rear platform standing always at zero.

The principal data required to fit these instruments is the diameter of the car wheels, the type of motor, and the gear ratio We illustrate the small generator in fig. 1203.

Brake Adjuster.—In order to save the labour of adjusting the brake shoes by means of turnbuckles or nuts, according to the design of truck, there has been introduced an automatic adjuster known as the Clay & Anger patent. In action it depends on the travel of the brake beam lever, which, when exceeding a predetermined limit, automatically draws the shoes closer to the wheels

Emery Brake Blocks.—Sometimes it is found that the car wheels are developing flats due to bad driving and other causes. These may generally be ground out, if not too bad, by the use of emery brake

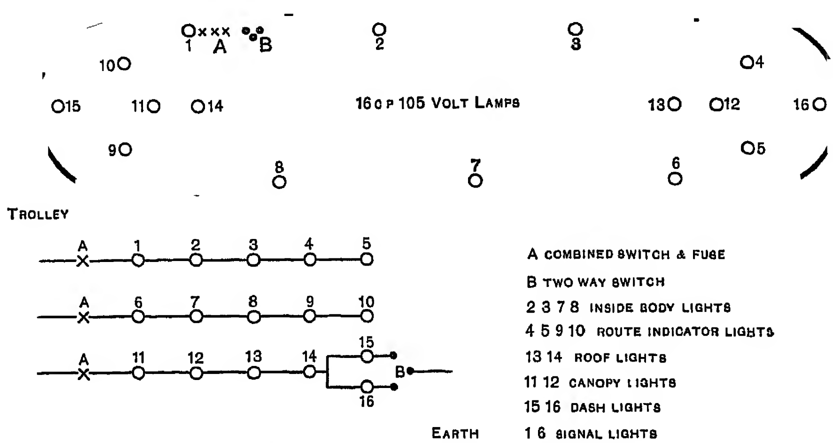

Fig 1204 —Car Lighting Diagram of Connections

blocks. These blocks are of steel or cast-iron with blocks of emery set in, and when carefully used will be found of much benefit

Car-Lighting Circuits—In fig 1204 we give a useful diagram for double-deck car wiring The wire used should be insulated with vulcanized rubber, heavily braided, of the 2500-megohm class. The size may be 3/22 S W G, which is amply large enough for one circuit It is usual for car work that all fittings shall be provided with $\frac{5}{8}$-inch brass thread nipples for the lamp-holders, which, contrary to American practice, where screw-socket holders are in general use, are of the bayonet-socket type, thus utilizing standard lamps, which, however, should be specially selected for series running.

Each circuit can be controlled by a small combined switch and cut-out, or by two separate devices. These should be capable of withstanding a dead earth anywhere on the circuit they control.

Bell Wiring.—We produce a diagram of a popular method of bell wiring for a double-deck car. The diagram is, we believe, quite self-explanatory (fig. 1205). We favour single-stroke bells of the gravity type, as being less liable to get out of order, and more convenient for code signalling.

Combined Watering Car and Track Sweepers.—A most useful adjunct to a tramway system is a car equipped for watering and sweeping the track. It has been found that a sufficient number of these cars on a system effect a very considerable economy in keeping the track in good running condition. We illustrate in fig. 1206 a car of this description, which is the standard type furnished for a large number of tramways by Dick, Kerr, & Co, Ltd. These cars are not only provided with rail-flushing pipes, but with a sprinkler arrangement as well for watering the road. The rotary brushes are particularly useful in snowy weather, and may either be driven from the car axle or from a separate motor. They are capable of being lifted up and thrown out of

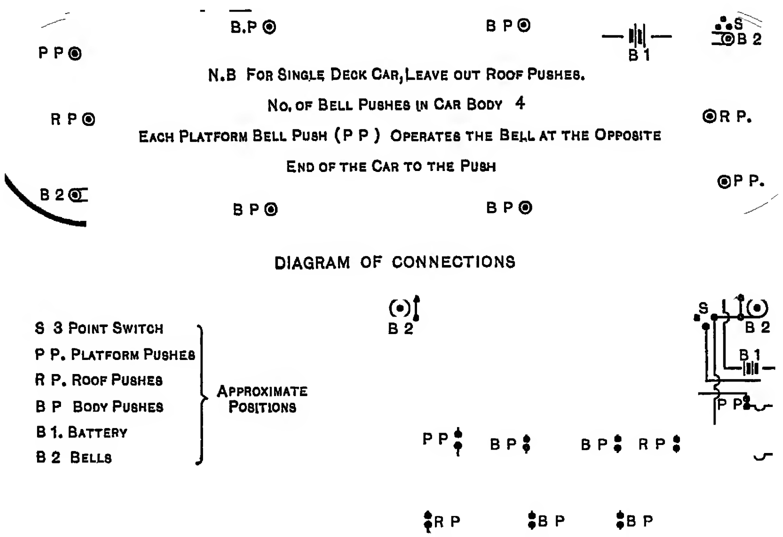

Fig. 1205.—Electric Bell Wiring Diagram of Connections

gear when not required. In addition, the cars are fitted with scrapers to clean the rail-head and groove, as well as the steel rail brushes previously described if required. Removable snow-plough attachments can be furnished for dealing with heavy falls This car when not otherwise required may be used as a locomotive for haulage purposes. Such cars are found useful even on small systems of twelve or fifteen cars, and on larger systems are indispensable. Sometimes air-compressors are installed on the car to augment the natural pressure of water; this enables the sprinkler to have a wider range, and gives the flush-pipes more force. The equipments and trucks of these cars should be the same as adopted on the passenger cars; it is, however, sometimes necessary to have the truck springs heavier and the journal diameters increased when very large tanks are employed.

When sweeping with the rotary brushes the car should be run on the series notches, and, in fact, should only be put into the parallel notches when not employing any of its appliances. Owing to the car

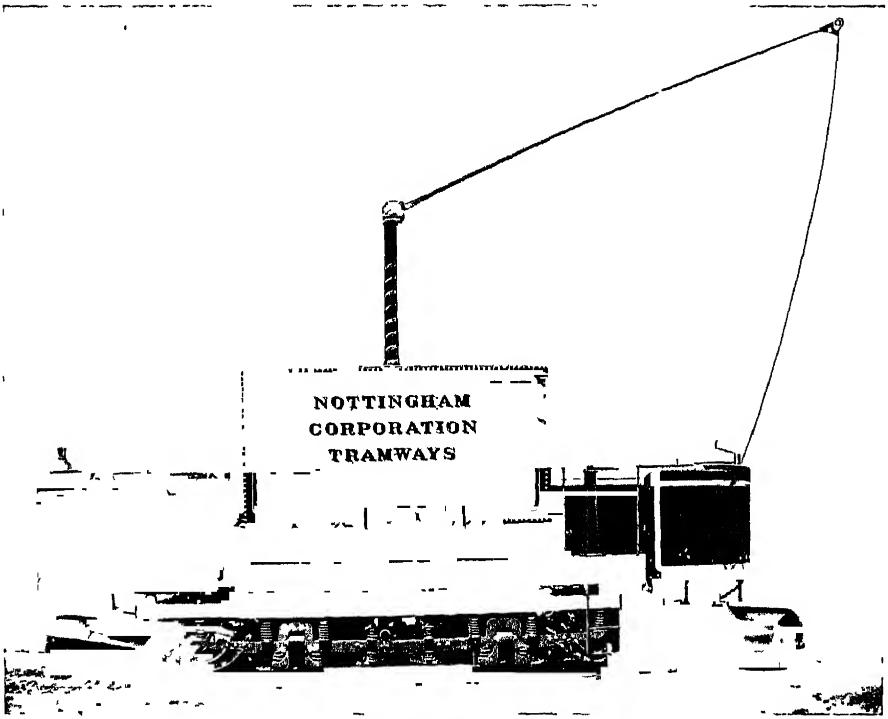

Fig 1206 —COMBINED WATER-CAR AND TRACK SWEEPER

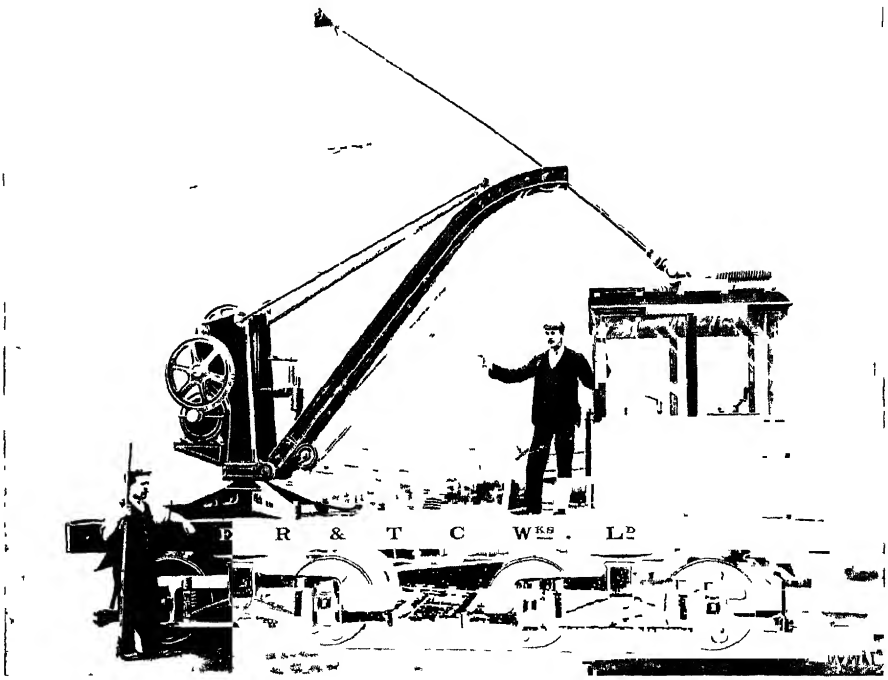

Fig 1207.—ELECTRIC LOCOMOTIVE

making no stoppages it is possible to run it amidst the other cars without causing any dislocation whatever. It is advisable that the tank should carry a sufficient supply to reach the terminus of any route, where, without inconvenience, it may be refilled from a stand-pipe.

Electric Locomotives.—This subject does not properly belong to a treatise on tramway rolling-stock, by which we mean electrically self-propelled street cars. There is no doubt that certain tramway systems find an electric locomotive of considerable service. We therefore illustrate in fig 1207 a locomotive in use at the Electric Railway and Tramway Carriage Works of Preston, which is used for shunting coal trucks, lumber trucks, making up trains of cars to be despatched by rail, &c. The locomotive has been found invaluable for this class of work, and during working hours has but a few moments of idleness. It is equipped with four 25-horse-power motors, and has in addition an electric jib swivelling crane

The Corporation of Liverpool are in possession of an electric locomotive which may be run either from the trolley wire or from accumulators, this latter method enabling it to leave the trolley system and work upon the lines and sidings of the railway companies as often as is desirable

Some Notes on Maintenance.—It will not be out of place, we hope, before closing this section, to give some hints which may assist those in charge of rolling-stock to successfully maintain it in proper condition The writer has had considerable opportunity of comparing the operation of tramway cars under widely differing methods of maintenance, and can most emphatically state that it is quite impossible to expect from any car equipments or accessories, no matter what make they may be, reliability when proper systematic arrangements are not made for their upkeep. Maintenance is of great importance not only as an engineering question, but from a financial point of view as well There is one maxim we would impress upon our readers, the importance of considering the engineering side of the question upon a broad and liberal basis. See in the first place that the cars are properly looked after, and having done this, then begin to look where economies may be made without prejudice to the engineering problem A few men properly schooled in their duties will do the work of an army of men left to themselves or improperly instructed in their routine work. In the first place, it is very dangerous to allow motormen or other unskilled persons to meddle with the adjustment of the equipments. The controllers usually suffer most in this respect, and the writer has known motormen, feeling their controllers work stiff (because they had not been properly attended to in the sheds), take some grease out of the motor bearings and smear it thickly over the controller contacts and fingers. Motormen should be instructed in the proper handling of the controller, and should be sufficiently familiar with its construction to make any small repairs on the road which may be absolutely necessary, otherwise they should be forbidden to lubricate or adjust them in any way. They, as part of their duty, are expected to watch the motor and truck bearings, and to take what steps are necessary if they are running hot; but they should not be allowed to interfere with the motor brushes, unless they find the shedmen have left a brush hammer up or something of that kind, and

should such be the case, they should report it to the shed foreman on returning to the depot when coming off duty. It is the imperative duty of the motorman to report all faults on his car, so that the shedmen may put things in order before the car leaves the next morning.

As to the work to be done in the shed, each car should be examined after it arrives in the depot, and men should be told off for this routine duty. For controllers there should be shedmen specially instructed in this work, whose duty it is to open up every controller during the night and wipe it over, lubricating the segments with a pad filled with cotton waste soaked in vaseline A very small amount of vaseline indeed should be used, one generally finds the tendency is to use far too much, this simply carbonizes on the contacts, causing trouble.

Once a week, say, each controller should be carefully overhauled, the fingers and contacts rubbed with a fine-cut file where scored at all, and all unevenness or nodules of copper smoothed off. They should then be finished smooth with fine emery cloth and oil, finally cleaned, adjusted, and vaselined. It is a common mistake to put too much pressure on the fingers, this causes the controller to work stiff, and more often than not in the endeavour to overcome this the contacts are heavily smeared with vaseline

The notching gear should be kept equally clean to ensure easy working, and this, too, should be part of the weekly overhaul. A good way of lubricating this is by making a mixture of fine graphite and machine oil to about the consistency of heavy cylinder oil; this should be painted sparingly on to the notch plate and rollers

After the controller is thoroughly cleaned it should be blown out with a pair of bellows to remove all carbon and copper dust; this should really be done before any lubrication is applied The cylinder bearings should be lubricated with a few drops of machine oil. Sometimes these bearings pinch the controller cylinder spindles, and this is a frequent cause in new controllers of their "wanting more vaseline", as the motormen generally report it Before leaving the subject, we may state that absolute cleanliness is quite essential to proper operation The writer was talking to an engineer in charge of over fifty cars, and was informed by him that for twelve months not one controller finger had been renewed, while on another system he was told they frequently had to replace fingers which were badly burnt, &c The controllers were of the same type, made at the same time, were subject to approximately equal wear and tear.

In relation to the maintenance of motors there is not so much to be said, and what nightly attention is required may be done by less skilful labour. Each night the brush-gear should be examined, and the bearing lubrication attended to; if grease be used, it should be pushed down in the box with a stick in order to prevent a cavity forming, as it sometimes does, over the journal, and thus allowing the bearing to go dry. Periodically the air-gap between the bottom poles and the armature should be measured and noted, so that the armature may be caught before it drops on its bearings on to the poles, and gets ripped to pieces When it becomes necessary to change the armature bearings, the whole motor

should be examined, bolts tried, shell and armature blown out, brush-gear cleaned, oil and grease wells and gear-case cleaned out, gear-bolts tried, and, if found necessary, the commutator turned up The wear to the motor axle bearings can be observed from the outside, and these may be changed when necessary. For lubrication it is important to use none but the best quality of grease or oil, it is no economy to use the cheaper qualities, which may, unless tested, appear to be quite as good as the higher grade

As to whether commutators should be cleaned with glass-paper or not is a point on which various authorities differ in opinion. If they can be induced to form a nice blue surface when cleaned only with white duck, or some such material, that appears to be the most satisfactory, as the life of the commutator is considerably augmented. This is not found by all to be practicable, and the other alternative is to clean the commutators, when running, with glass-paper. For this purpose it is better to have a special tool of wood made with a suitable handle; the glass-paper is put on several layers thick, so that when worn a leaf may be torn off This tool may be used with safety when the motors have current through them, a fulcrum may be made of one of the brush-holders to steady the tool After cleaning, the brushes should be lifted and wiped over with a vaseline rag before being replaced

It is very often necessary to lift the car bodies from the trucks, and a most useful set of jacks for this purpose is made by Charles Booth & Co, of Liverpool, and by Messrs George Milnes & Co, car builders They consist of four geared pedestal jacks, and two steel cross-beams to go under the car After seeing all free and clear between the truck and car body, it is a matter of a few seconds to lift the car to any desired height Pit jacks on wheels should be provided in each depot for dropping the motors or armatures from the cars. While on the subject of jacks the writer may say he infinitely prefers those of the screw type, as being safer, though possibly slower, than hydraulic It is never safe to leave a job suspended on an hydraulic jack in case there is any leakage going on, in which case the jack sinks, possibly causing considerable damage

Even on small systems one at least of the car depots should be fitted up with facilities for carrying out repairs, and the plant can conveniently be run by one of the tramway motors with suitable controller. The most useful tools, besides the necessary benches, vices, and hand-tools, will be an hydraulic wheel-press, a back-gear screw-cutting lathe for taking axles, armatures, and smaller jobs, a drilling machine, a shaping machine, a forge, anvil, and tools, a baking oven, and where an armature winder is employed the necessary outfit for his work.

The repair depot should be furnished with cranes of the jib or other convenient pattern, for lifting weights out of the pits, and for lifting them into the tools. Wheel trolleys should be provided for dragging the heavy jobs from the pits to the tool-room. We have mentioned only those tools and appliances which we consider essential to all systems of any pretensions whatever. The larger the system, of course, the greater the advantage of furnishing more special tools and appliances.

8. Electric Boats and Motor-Cars

CHAPTER I

ELECTRIC MOTOR-CARS

The construction of electric automobiles has not in its main features changed in any important degree in the past seven years The designs originating in America and France are most largely used, and are those now being most closely followed by the leading makers in England Some English designs have, however, been followed, but English makers have not achieved the commercial success of those who are working in connection with transatlantic firms or on their lines

The advantages of electric motor propulsion, as compared with other methods, are, from mechanical and convenience points of view, as fully recognized now as they were six or seven years ago, when promises were more lavish and practical success commercially unproven.

Now as heretofore the secondary or storage battery provides the limiting element as to power, range of travel, and cost of working Its weight imposes demands as to means of carrying it, increases cost of propulsion, and decreases the life of wearing parts. Improvements in the strength of the electrodes and methods of connecting-up have been made, so that the proportion of effective weight to dead-weight is greater with a given capacity and discharge-rate than formerly, and cost of renewals has been reduced The types of batteries most in use are well-known developments of the grid and hydrated-lead peroxide pasted forms, but well made, carefully maintained, and sufficiently frequently charged for best working conditions

The distance which an electric automobile can cover on one charge has increased considerably during the past few years, the increase being partly due to improvements in the transmission gear, making the parts of better material and workmanship and of less weight, reduction of weight of the vehicles generally, in the size of the battery electrodes, and in the weight of the cells and carriers

The use of electrically-propelled carriages has increased very rapidly of late, for town use, by those to whom the greater cost of running, as compared with the petrol car, is of little importance as compared with the quiet and easy running of a vehicle, which, as in the case of those maintained by the Electromobile, the Oppermann, and the Krieger Co., is always kept in working order and at call at any time by the owner or

hirer. This use has naturally undergone increase, as the organization of a large establishment specially devoted to these vehicles relieves the owner or user of all maintenance and technical considerations.

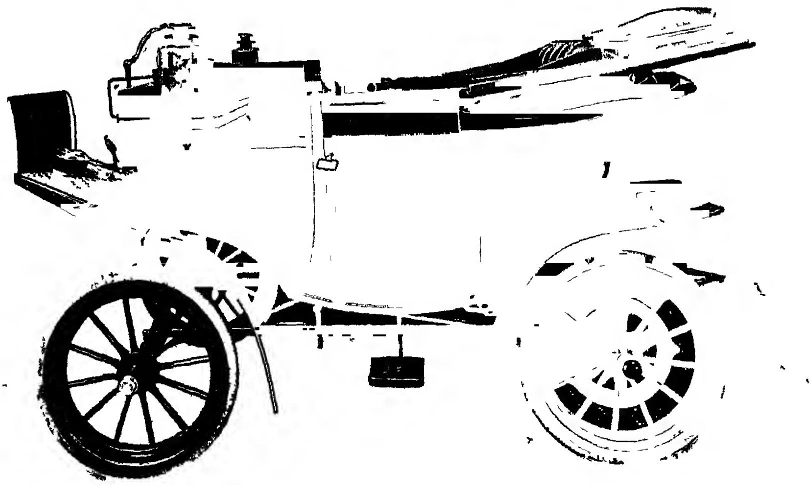

Fig 1208 —Electric Landaulette

As compared with the electrical cabs which were run in London for some months in 1899, vehicles of the same capacity may be said to be about 30 per cent less weight, and light open vehicles carrying two persons 25 per cent less weight.

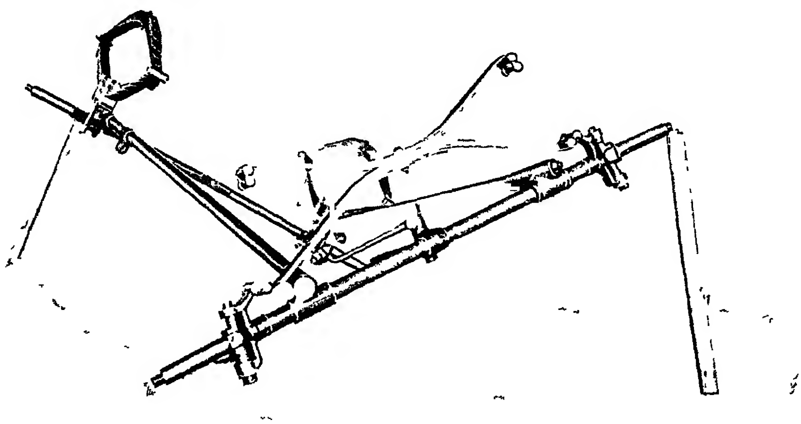

Fig 1209

A landaulette constructed by the City and Suburban Electric Carriage Company, London, is shown by fig 1208; and some vehicles of this type are still in service The maximum mileage under favourable conditions, and with what is known as the City battery, is 40 miles, and the maximum

speed 12 miles per hour. The battery is carried in the boot at the back and in a modified form of the carriage a battery-box is carried in the front also, the weight being about equally distributed and the maximum mileage somewhat increased The frame of the carriage is made on the lines of the Riker and the Columbia vehicles referred to hereafter, the frame being so designed that horizontal rigidity is obtained, while vertical freedom of the parts permits the frame to accommodate itself to any irregularities of road surface Fig. 1209, from a photograph of one of the

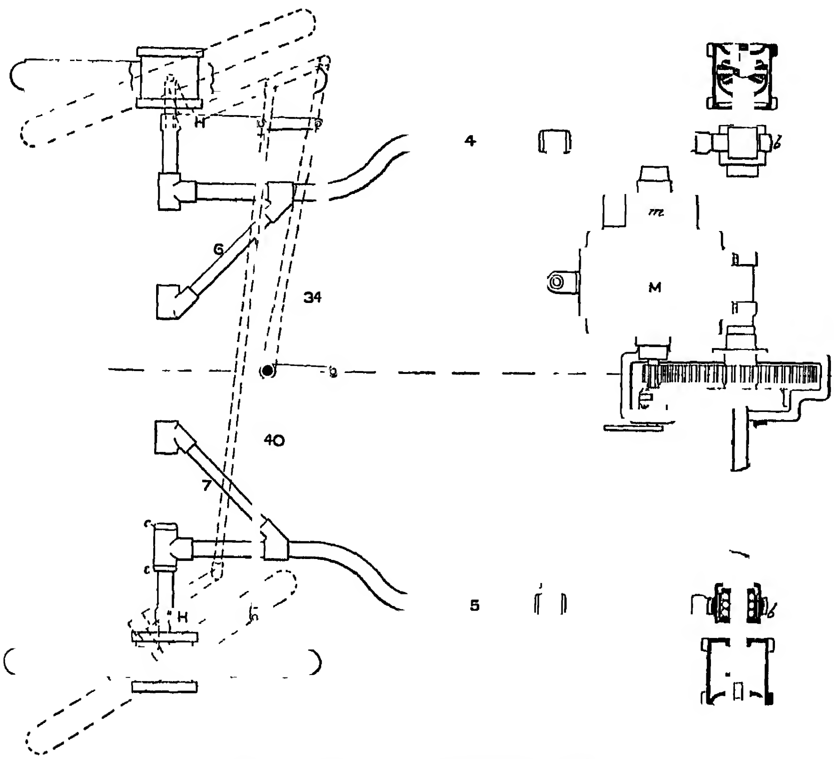

Fig 1210.—Plan of Frame of Riker Electric Car

frames, independent of the body, shows how completely this vertical freedom is obtained, one axle being tilted through a large angle in one direction and the other axle in a similar way in the opposite direction

When the body is attached to the springs the tilting is of course restricted very much, but the frame is free from the stresses otherwise due to the rise and fall of the wheels through any range of which the springs are capable.

Fig. 1210 shows in plan the arrangement of the frame of the Riker electric car and its gearing. The longitudinal tube 4 is rigidly connected to the front cross-axle tube and the diagonal tube-stay 6. The longitudinal tube 5 is pivoted between collars *c c* on the front tube, and the diagonal stay 7 fits freely upon the front-axle tube. The cross-stay upon which the motor M rests fits freely upon 4 and 5, and is kept in place by collars.

complete freedom from stresses due to differential lifting of the wheels is thus avoided. The arrangement of the steering gear is clearly shown by fig. 1210, as well as the single reduction gear and brake enclosed in

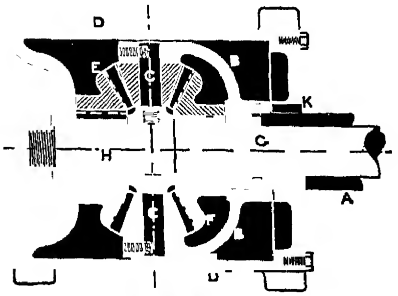

Fig 1211

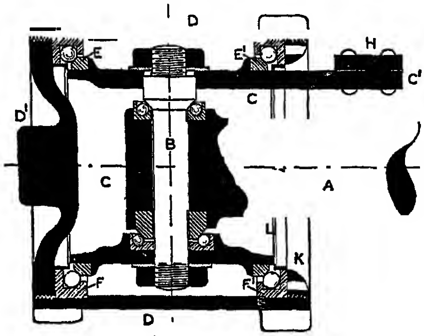

Fig 1212

a case in the centre of the driving-axle. The latter consists of an exterior tube carrying ball-bearings at its ends. Within this is a tubular axle carrying the near driving-wheel, and part of the differential gear in the nave of the

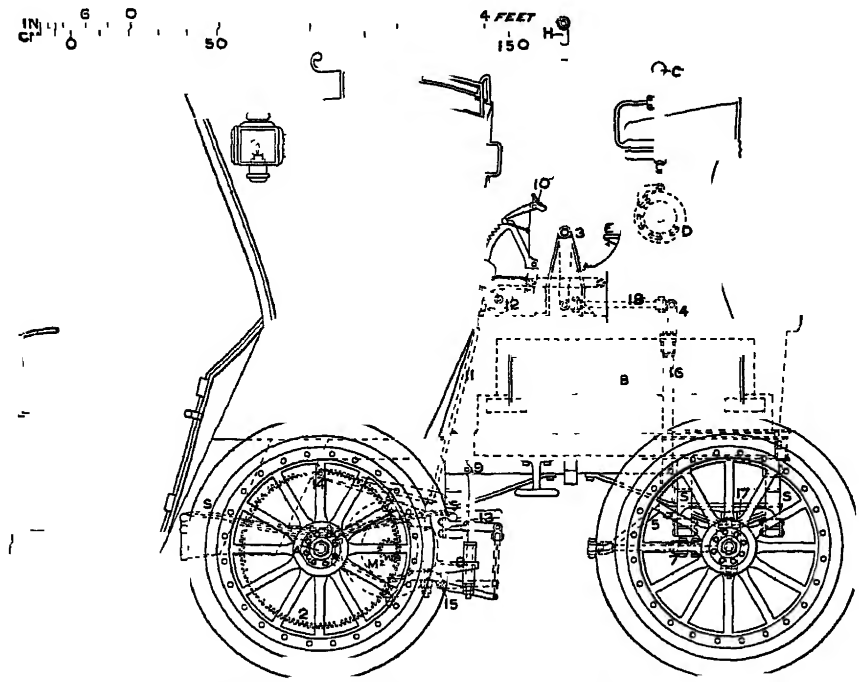

Fig 1213 —Electric Cab (Morris and Salom, Philadelphia)

off-wheel. Within this tube is a solid axle fixed in and driven by the inner half of the differential gear and centred in the off-wheel nave. The tubular live axle therefore drives the differential and off-wheel, and carries

the load The interior solid axle transmits the torque effort to the near wheel

The construction of the differential gear is shown by fig. 1211, in which A is the tubular live axle, B the crown-wheel of the differential carrying the differential pinions on pins C C, which drive the bevel-wheels E and F respectively, fixed in the nave of the off wheel and on the solid axle G for driving the near wheel. The arrangement is ingenious, and secures a through axle instead of a divided one, but the gear is necessarily small, which is a practical objection

Fig. 1212 shows the arrangement of the steering-wheel naves and axle ends. The fixed axle A carries a ball-bearing-supported pin B fixed in

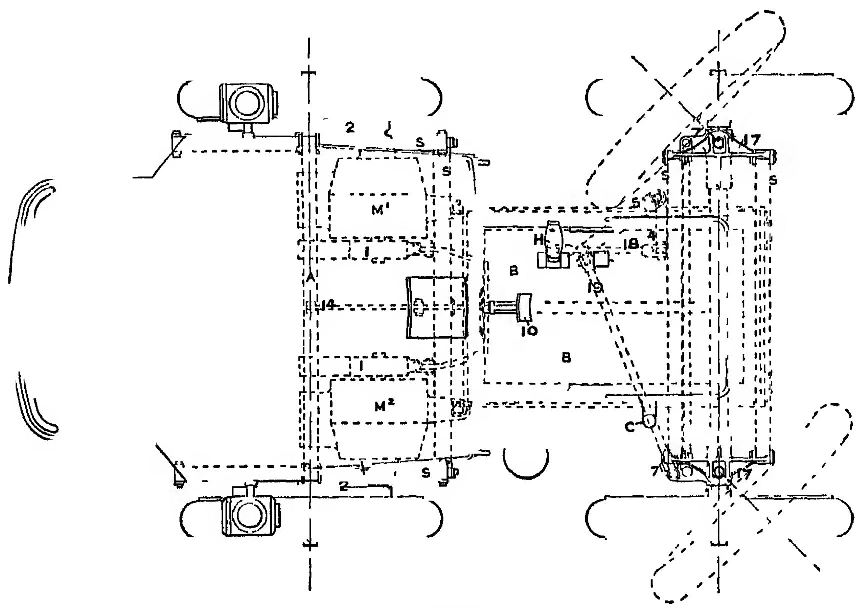

Fig 1214—Electric Cab Plan

the internal cylinder C, upon the ends of which are ball-bearings E E^1, upon which the wheel nave D revolves. Extending from the cylinder C is an arm C^1 to which the steering arm H, figs. 1210 and 1212, is attached. The steering-wheel pivots are thus in the centre of the wheels in the plane of the tyres, and impact received by the wheel is not imparted to the steering arm H or steering handle.

A vehicle of which considerable numbers have been made by Messrs. Morris and Salom of Philadelphia is shown by figs. 1213 to 1218. This is front-driven by two small Westinghouse motors gearing by pinions on the outer ends of their spindles, with internal-toothed rings fixed to the wood driving-wheels running on large pneumatic tyres. In this cab there is no separate under-frame, the machinery being carried by and partly mounted on the driving axle, as shown in figs. 1213, 1214, and 1215. The body is carried over the front axle by long side springs S, connected at their rear ends by a transverse spring similar to the two transverse

springs S S which support the body over the rear steering axle. Upon the ends of the strong tube forming the rear axle are fixed the steering-fork malleable castings 17, on the upper part of which yokes are formed to carry the ends of the cross springs by links as shown. At their centres all the cross springs are fixed, as shown by fig. 1215, to transoms connecting the sills of the body frame.

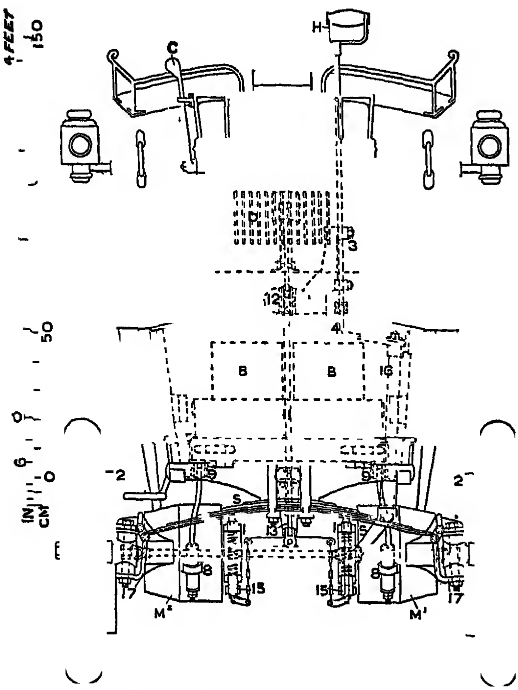

Fig 1215 —Electric Cab Front Elevation

The motors M^1 and M^2 are pivoted on the front axle by extensions of their field-magnet castings, on the opposite side of which are formed supporting arms seen on the plan, fig 1214, and at 8 8, fig. 1215. Through holes in the ends of these arms pass supporting-rods pivoted at 9, fig 1213. Above and below the arms are rubber buffer-collars, figs 1213 and 1215, and J J, fig. 1216, which give a cushioned support to the motors as carried by these arms, and soften the upward jerks due to momentum as the vehicle runs over rough ground A considerable part of the weight of the motors is thus spring-supported, and a constant radial distance is maintained between the armature spindle and the axle, upon which the wheels they drive rotate

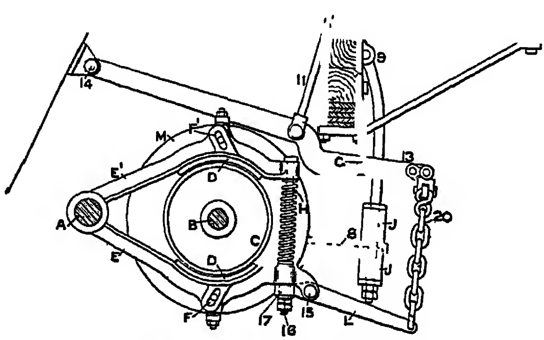

Fig 1216 —Electric Cab Brake Gear

The steering is effected by hand-lever H, pivoted at 3 on the right hand of the driver The lower end of this lever pushes and pulls a rod 18, which actuates a lever 4 on a vertical spindle, on the lower end of which is a lever 5 engaging with a rod 19, by which a projecting arm on the near pivoted axle is actuated, and thereby the off axle by the connecting-rod shown. The axes of the steering-axle pivots are inclined so that, if produced, the point of incidence with the ground would

be near the wheel, and the effect on the steering gear of meeting an obstruction is lessened.

There are two brakes, both on the armature spindles of the motors. The brake gear is clearly shown in elevation by fig. 1216, and the method of coupling the two so that both shall be equally operated by the pedal 10, rod 11, lever and balance-bar 13, and chains acting on the levers 15 is seen in fig 1215. The two brake-arms E and E^1, fig 1216, are pivoted at A on the leading axle, and the pull of the lever L, pivoted at 15, upon the rod 16, pulls the two arms E and E^1 equally upon the drum C. These brakes are of good design and act equally forward and backward, but by

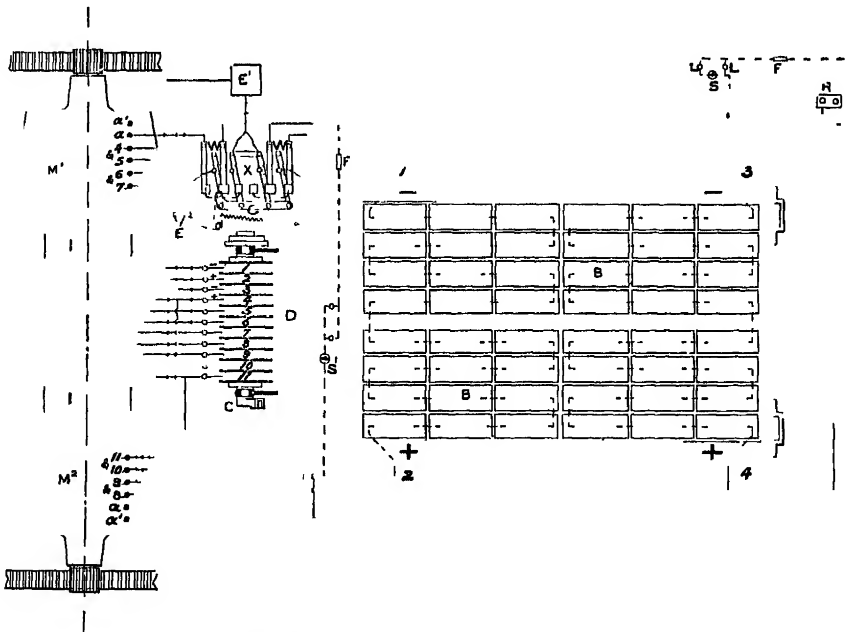

Fig. 1217 —Plan of Electric Cab, showing Battery

coupling the two with a balance-lever and chains their trustworthiness is lessened, because if one becomes defective, or the chain of one or the balance-lever is broken, both brakes become useless, and there are no others on the cab

The motors are series-wound, each of about 2½ horse-power at 700 revolutions per minute.

The battery is carried in the large box under the driver's seat, and consists of 48 chloride cells of 5 plates, weighing in all about 11½ cwts They were said to be capable of a discharge capacity of 100 ampere-hours at 80 volts at normal discharge rates, and this rate is claimed now, and even a higher rate, from the batteries in common use on other cars. The cab made as shown was calculated to run about 25 miles on one charge on good street and road surfaces.

The battery is, as was usual, divided into two sections (see fig. 1217), and the motor fields are wound in sections. Various combinations of con-

nections in series and in parallel can from this be obtained for the three distinct current and voltage requirements for three speeds forward, and for reversing. The battery-tray (see fig. 1217) makes its own connections by means of rubbing-plates 1, 3, and 2, 4 A rotary controller is employed, indicated for convenience at D, its actual position when used in the brougham with driver in front. The scheme of connections is the same on both vehicles The controller has 11 contact-plates coupled up to the motors in the order of the numbers as shown At X is the main working switch. At *a* and *a'* are the connections to this switch for forward and backward running, worked by the pedal E, figs. 1213 and 1217. This pedal is normally in the position for keeping the switches in contact for forward running, as shown in the diagram (fig 1217) of the scheme of connections. The depression of the pedal cuts out the right-hand set W of switch connections pivoted to the bar G for reversing, and throws in those coupled with the wires *a a'* of each motor A separate switch C is conveniently placed for completely cutting out all current in emergency, or for stopping and leaving the vehicle in safety by the removal of a key. A dual charging plug is indicated at R for charging the batteries in place At S is a switch for two lamps in the battery boot for examination purposes, and at F is a fuse in the charging circuit. A fuse is also inserted in the circuit for the carriage lamps, which is controlled by a switch S^1 under the driver's seat.

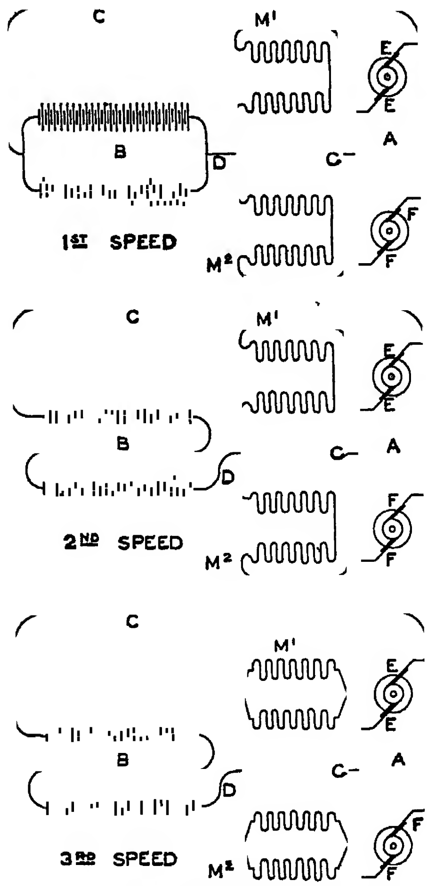

Fig 1218 —Electric Cab Controller Connections

The controller connections are illustrated by the three diagrams of fig 1218, for the three speeds. In each case the two sets of batteries are represented at B, and D represents by one wire the whole of those shown by fig. 1217.

For the first speed the two batteries are coupled in parallel, with the field-windings of each motor M^1 and M^2 in series.

For the second speed the batteries are coupled in series, and the field-windings are still in series.

For the third or highest speed the batteries are in series, and the field-windings in parallel, as indicated

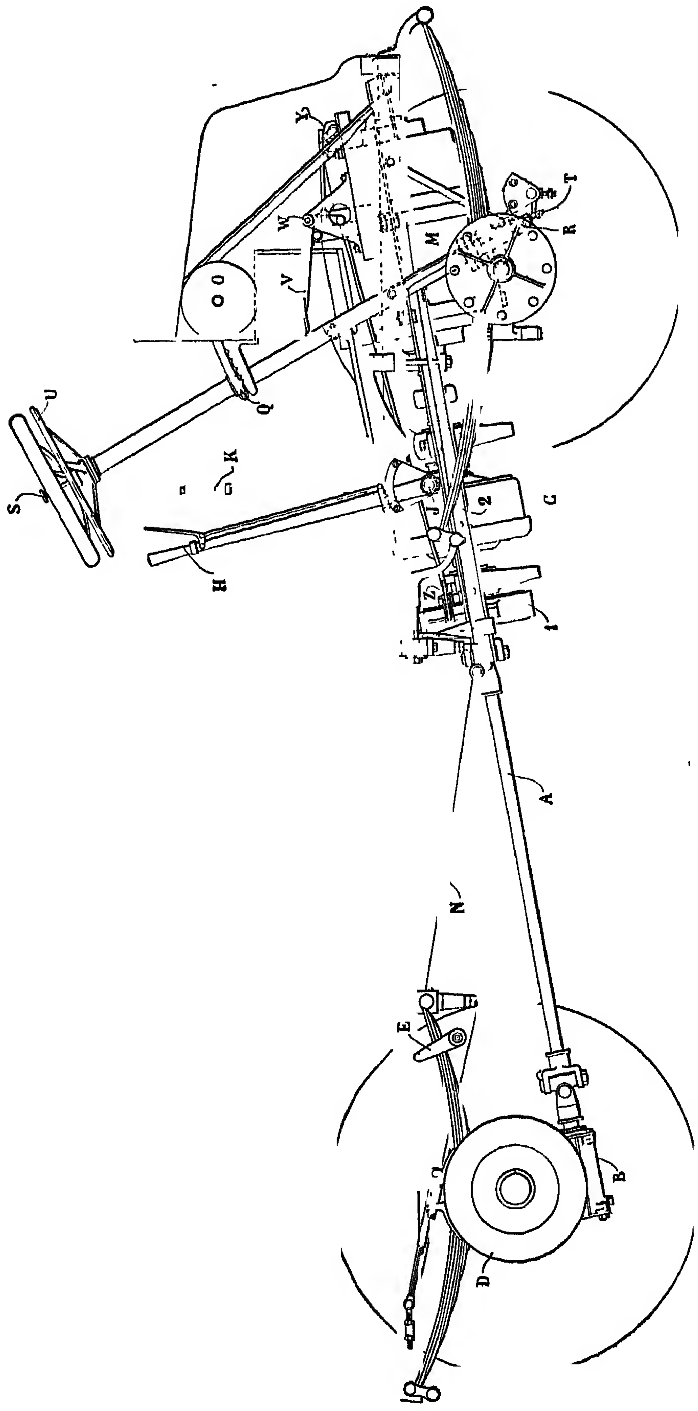

Fig 1219 —Side Elevation of Under-Frame and Running-Gear of Electric Vehicle (Electric Motive Power Co)

In the diagrams the field-magnet systems of the motors are represented by the windings M^1 and M^2. G in each case completes the circuit through the armatures with the brushes E and F on their commutators In each diagram the motor armatures and field-magnet coils are connected in parallel. The connections of the two field-coils on each motor are the same, *i.e* in series for the first and second speeds, and in parallel for the third speed. For the first speed the batteries are connected in two parallel series and give a current at 40 volts. This arrangement gives a maximum torque

When in position for the second speed, the batteries being in series, the full E.M.F. of about 80 volts is available with the same conditions as to motors, motor field, and armature connections. When in position for the third speed, it will be seen that the full E.M F. is used with all the field-windings in parallel. This reduces the total resistance and allows the battery to give a high discharge with increased speed.

The Columbia Co., of Hartford, Connecticut, were early among the best designers and constructors of electrical vehicles, and many of the vehicles formerly in the City and Suburban Co's central station "Niagara" were of this company's make, or constructed here on the Columbia lines Some of the vehicles were made with a single motor and second motion shaft fitted with a differential gear This system, however, has been entirely given up in favour of the two separate motors independently actuating rear driving-wheels The Columbia Co. made experiments on an extensive scale with many different forms of secondary battery, and materially assisted in the practical knowledge possessed to-day of suitable battery construction for automobiles. A valuable series of experiments on this subject was conducted under the auspices of the Automobile Club of France in 1899, and the Pope or Hartford battery was amongst those that underwent the tests. As an example of the Hartford or Columbia Co's vehicles, some particulars may be given of a stanhope phaeton capable of carrying four persons The carriage complete weighs, with batteries and in running order, 25½ cwts, the batteries themselves weighing of this nearly 10 cwts The expenditure occurrent on good level roads was found to be from 145 to 150 watt-hours per mile, and the recharging current about 220 watt-hours per mile to 230, showing a high battery efficiency, viz about 0 65 The expenditure on good smooth level roads at 10 miles per hour represents about 2 horse-power net, at which rate the mileage capacity of the vehicle has been stated to be about 35.

Fig 1219 is a side elevation of the under-frame and running gear of an electrical vehicle, made by the Electric Motive Power Co, of Balham, from the designs of Mr. Percy W Northey, and figs 1220 and 1221 are illustrations[1] of the worm driving gear and differential gear used in the same car. The body of the vehicle is not shown, but this is made in the form of the brougham, or Limousine, or Tonneau, as required. It is a departure from all previous arrangements of electrical vehicles, the general manipulation being similar to that of a petrol car. The motor M is placed with its armature lengthways of the car, the motion being transmitted through a magnetic clutch C to a jointed shaft A to the

[1] *Motor Vehicles and Motors*, by the author

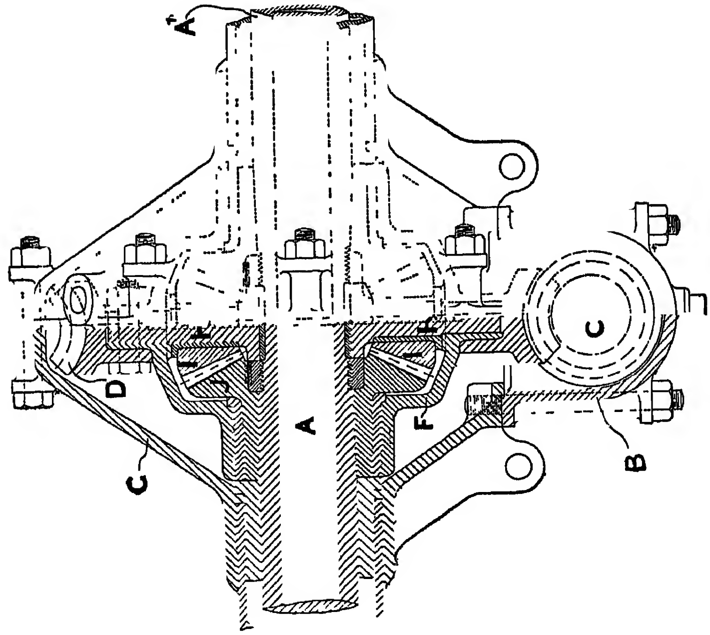

Fig 1221

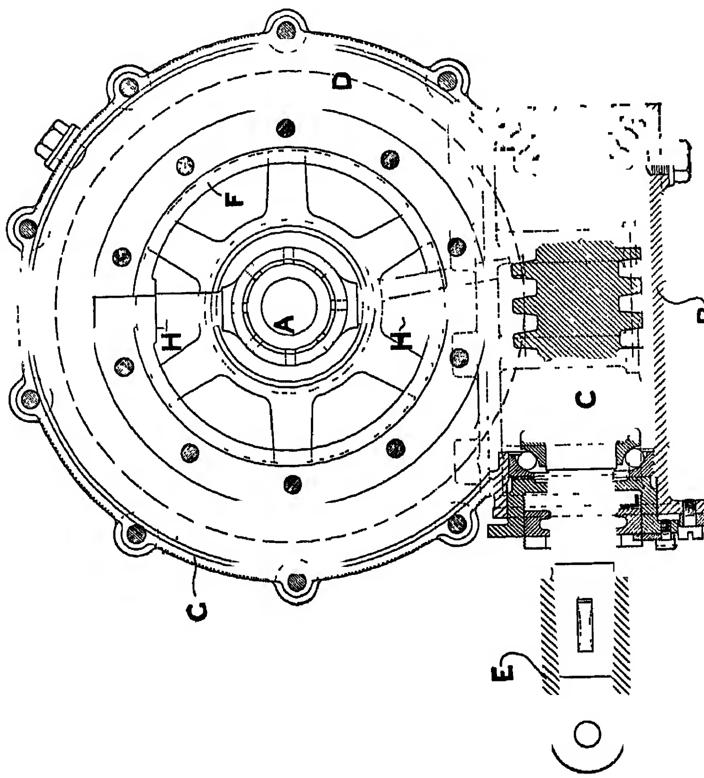

Fig 1220

short worm spindle in the box D, seen on a larger scale in fig 1220, the worm gearing with the crown-wheel D of the differential motion The magnetic clutch C, shown in detail in fig. 1222, comprises also a two-speed gear. In this A′ is the shaft driven by the motor, and carrying a bevel-pinion and the annular electromagnet C fixed upon it E is a collecting-ring, and C′ a stationary magnet. Between the two electromagnets is an armature F running free on the transmission shaft A, and capable of a limited movement between the two electromagnets. The armature is connected to a box H, to which a bevel-pinion loose upon the shaft A is fixed. The transmission shaft A is hollow at its inner end, and the shaft A′ runs within it On the inner end of A are short spindle or pivot arms J, carrying the two bevel-pinions, always in gear with the pinion fixed on the inner end of A′ and that loose on the inner end of A.

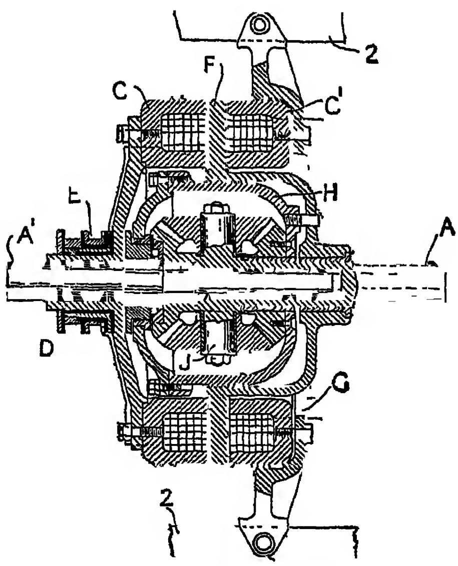

Fig 1222

When the rotating electromagnet C is excited, the armature F, and consequently the pinion fixed to the box H, rotate together, thereby driving the shaft A at the speed of A′

To obtain the low speed, the electromagnet C is disconnected and the magnet C′ excited. The armature F is then held, and with it the pinion fixed to H. The rotation then of A′, and the pinion fixed to it, causes the pinions on the arms J to roll round the pinion held by H, and thereby give motion at half-speed to the shaft A.

To avoid the effect of remanent magnetism, and to enable the armature F to leave the magnets immediately on opening circuit, the faces of the armature F are electroplated with copper. The worm and wheel driving gear, shown by figs. 1220 and 1221, run in oil in the containing case, the worm being a five-thread screw capable of driving, or being driven, by the worm-wheel, so that the motor may act as a generator on down-grade runs for recuperating the battery. The worm spindle runs in ball-thrust bearings at either end, and adjustable by the nut and check-nut arrangement seen at L. The driving axle A A′ (fig. 1221) is hollow, and is driven by the bevel-pinions I I of the differential gear carried on the arms H H, seated in the rim of the differential crown-wheel F, which carries the renewable worm-wheel ring D. The pinions I I drive equally or differentially the bevel-wheels J, equally if the driving-road wheels are running a straight course, or differentially if a curve is being traversed

The operating apparatus, apart from the motor and the gear described, comprise a controller moved by a pedal, a switch by means of which current may be generated on steep down-gradients, and used as a recuperating current to the batteries, or for accelerating, and a reversing switch moved by a side-lever K (fig. 1219), as in petrol cars. The generation of a recuperation current may be employed as a brake. Two other brakes are provided—one a double-acting brake applied by the lever H, acting differentially on brake-drums on the driving-wheels, the other operated by the pedal V pivoted at W, and tightening a band (fig. 1219) on the drum on the round-part end of the shaft A (fig. 1222). When this brake pedal is depressed, the motor circuit is broken by the switch Y

The controlling and steering operations are effected by means of the steering-wheel and steering-pillar as a lever. Under the steering is a detent wheel U The pillar is capable of to-and-fro motion, and thereby operates the controller drum at O for obtaining one or other of the several electrical combinations of motor windings and battery cells by which any of the four speeds forward or reverse are obtained.

The position for forward motion is obtained when a detent at Q falls into one of the corresponding notches in the quadrant thereat This detent is raised when the wheel U is lifted by the fingers, the hand resting on or being over the steering-wheel. Either steering or controller operations are thereby effected with one hand at any position for steering

When it is desired to operate the low magnetic gear, the button S at the centre of the steering-wheel is depressed, and to run direct or at full speed the button is raised This movement of the button S operates the two-way switch T at the bottom of the steering-pillar

The battery consists of forty-four cells, having a capacity of from 160 to 180 ampere-hours when discharged in 4 hours. In some forms of carriage the battery is carried in two boxes, one in front and one behind

Fig. 1223 is an outline side elevation of a brougham, as made by the Electromobile Co, Mayfair, London, in which the battery-box B is carried beneath the straight-line frame F supporting the body The motor M is suspended from the axle, and drives the wheels through a differential gear and solid and tubular live axle, the suspension of the forward part of the motor being by suspension and buffer spring The driving gear is carried in an oil-tight gear-case, as shown in the Riker plan (fig 1210), an arrangement which works most satisfactorily. In this vehicle the controller is under the driver's seat, but in others made by the same company it is placed vertically in front of the steering-pillar, and two motors are employed. E.P S. and Contal batteries are employed The arrangements for recuperation are distinct from the controller, and are controlled by a pedal which permits or cuts out recuperation on the first and second speed. A second pedal controls a series of resistances which modify speed forward or modify recuperation.

Many modifications of the grid and paste, or lead and hydrated peroxide of lead batteries, have been tried by the different makers of electrical vehicles both at home, and in France, Germany, and America. Zinc and

lead peroxide cells have also been tried, including the Lee-Coll, with lead and zinc and cadmium, and latterly a good deal has been heard of a battery upon which Mr. T. A. Edison is working in America with perforated steel electrodes, said to be filled with nickel oxide and graphite or iron and graphite for the negative and positive respectively. The E.M.F. is 1.3 volt, and the capacity of one cell, having twenty-four plates and weighing 18 lbs., is given as 200 watt-hours, or 11.2 per lb., the cells being 14 inches high by $5\frac{1}{2} \times 3\frac{1}{2}$ inches. The discharge rate is said to be very high, and rapid charging does not affect them. They may, it is said, be run down to no voltage without damage, but are not in practice run to below 0.75 volt. The chief advantages claimed beside these are strength and freedom from local action. As to capacity, in comparison

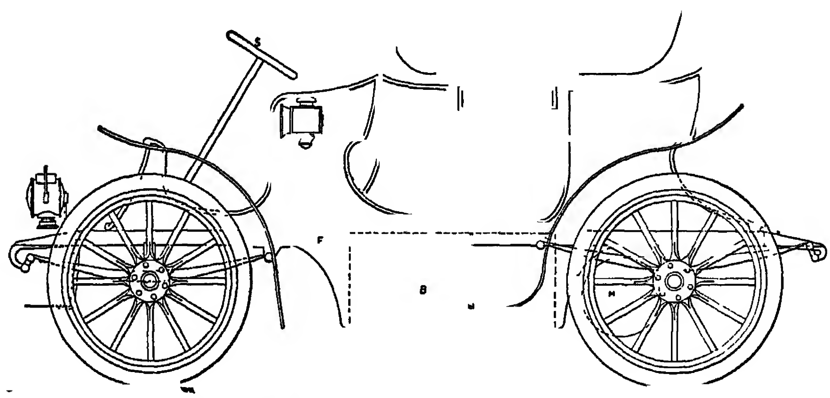

Fig 1223.—Side Elevation of Electric Brougham (The Electromobile Co.)

with this it may be noted that the Fulmen pasted-lead electrode battery has long been credited with at least 11 watt-hours per lb of complete cell with a discharge E.M.F of 2 volts, but these cells cannot be run down below 1.7 with impunity, and as with all lead batteries the mechanical strength is not what might be desired. It has, however, yet to be proved that this is greater in the newer cell.

The results of the trials above alluded to of the Automobile Club of France, made in 1899, are given below, but it may be remarked that several of the makers of the electric vehicles now claim better results after trial. In the Club trials, the sets of batteries were each charged with 24 amperes at 2.5 volts per cell, and discharged at rates varying from 20 to 100 amperes with occasional periods of rest, as in practical use, the practical conditions being further imitated by mounting the batteries on vibrating cradles to simulate the road jerkings of a vehicle. The trials were stopped when the cells showed signs of failure which would reject them in practice.

TESTS OF BATTERIES MADE BY THE AUTOMOBILE CLUB OF FRANCE, 1899

Name	Electrodes. +	Electrodes. −	Weight Lbs	Total Number of Discharges	Total Kilowatt-Hours	Ton-Miles at 100 Watt-Hours per Ton-Mile.	Efficiency fell from	Total Kilowatt-Hours per Lb of Cell.	Cubic Feet of Space required by Battery
							per cent		
Tudor .	Formed	Pasted	236 5	135	135 8	1358	67 to 60	0 57	2 2
Blot Fulmen .	,,	,,	215 6	132	143 9	1439	76 ,, 68	0 67	2 0
Fulmen.	Pasted	,,	148 5	98	101 9	1019	77 ,, 66	0.67	1.36
Phœnix.	,,	,,	202 4	102	118.8	1188	75 ,, 66	0 5	2 01
Pope .	,,	,,	220 0	135	155 5	1555	74 ,, 70	0 7	3 0

The highest output was obtained with the Pope battery, which gave an output equal to running a vehicle 1555 ton-miles with 4 per cent loss of efficiency, but occupied a large space, the positive electrodes being of cylindrical form The pasted Fulmen cell has flat electrodes, occupies little room, and gives a high output, and on this account it is almost universally used in France

Recent tests of storage-batteries in America and in England have[1] shown much better results, and in France 3000 ton-miles is at present obtained with a loss of efficiency of about 10 per cent Storage-batteries for electric automobiles can be obtained which will give 1 horse-power-hour for 67.2 lbs weight of complete cells, with a durability of 3000 ton-miles, allowing 10 per cent loss of efficiency and an efficiency of charge and discharge of 80 per cent This means that an electric vehicle, weighing, say, 6 cwts, with a battery weighing 6 cwts and a load of the same amount, could run 10 miles per day for 330 days in the year, *i e* 3000 ton-miles, taking 100 watts per ton-mile, at a loss of efficiency in the battery of 10 per cent. Vehicles of this weight are little used

The City and Suburban Electric Carriage Co (1903, now inactive) was the largest user of batteries for carriage purposes Most of the batteries used are of the E P.S. automobile type. There are forty-four cells in a battery, having a capacity of about 130 ampere-hours, capable, it is stated, of running one of the standard broughams 35 miles on good ordinary roads as met with in most town work These broughams are propelled by two four-pole Westinghouse motors of 2 5 horse-power, and the batteries will usually run about 1600 miles before a new set of positives is required

About 230 vehicles were at one time at "Niagara", systematically housed under a very complete system of usage, examination, repairs, and charging The chief causes of failure, namely, overwork, under-feeding, and neglect of repair, are eliminated The methods adopted in the very complete organization of plant and staff may be costly, but nothing is so costly as the distrust and uncertainty that has always

[1] *Proc. Inst. C E.*, vol. clii., 1903 Paper by Mr H. F Joel.

resulted, and must result, from incompleteness in supervision and maintenance, especially when aggravated by insufficient numbers of vehicles and consequent over-mileage between examinations and renewals.

Although the accumulator-propelled electric vehicles which have been illustrated are not of recent design, they yet remain typical of some of those now in regular use. The changes that have occurred are principally those affecting details, and resulting in either reduction of noise, convenience of control, or improvement of running and in appearance.

The largely used Electromobile vehicles have undergone changes of this nature, but they, in common with others, are of the two-motor, or equivalent double commutator single motor, series parallel control, gear-driven type.

The Krieger front-driven cars are of distinctive design as regards the radial suspension of the motors about the front axles, the rear wheels being only load bearers for the frame and carriage body. The earlier design provided for partial spring suspension of the motors, but in the recent design this commendable feature has been abandoned, and a very compact, completely encased arrangement of the internally toothed single-reduction gearing, previously employed, is now used

The type of car constructed by the Silvertown Company is different from any other as regards the arrangement of motors and transmission gearing The front and back axles are provided with similar motors and driving and differential gears and are driven independently There is no mechanical interconnection of front and rear driving wheels, although when both motors are in use they are subject to the series parallel control, and are thus electrically interconnected The controller is so designed that either the front, back, or both motors may be used, and the failure of a part affecting one of the motors does not prevent the use of the carriage A switch is provided with three working positions corresponding to the front, back, or both motors in service

The Lohner Porsche design of motor has been incorporated in the new Mercedes electric car, and the same form of motor is used in the Mercedes-Mixte petrol electric car. The principal feature of interest is the use of motors in the position usually occupied by the hub of the wheel The armature is stationary, and the 12-pole field ring rotates around it as part of the road wheel. The commutator is of face plate form, and the brushes rub radially on the vertical face As the motors rotate with, and at the speed of, the road wheels, they are necessarily heavier than motors of the ordinary type carried on the car frame, and running at a proportionately higher speed due to the speed-reduction gear usually employed.

The motors are, however, of favourable form, and are in a favourable position for air cooling, so that increase of weight per unit of output, due to the low speed of rotation, may be partly compensated by increased overload capacity. Losses in power transmission are largely reduced by dispensing with all gearing.

The Védrine electric carriage of French origin has, so far, been little used in this country. The type of motor and method of control distinguish it and call for brief reference. A compound wound motor is used, so

wound that the field may be obtained from the shunt winding alone, and a switch is provided by means of which the series winding may be short-circuited after the car has been started and has attained a road speed of two or three miles per hour. Almost the whole of the speed regulation of the car is effected by regulating the shunt current. A five-stage starting resistance is used in series with the armature, but for all speeds above two or three miles per hour the control is by shunt regulation As there are eleven contacts to the shunt regulating switch, and the five contacts to the starting switch, acceleration of the car is gradually and smoothly obtained, and the movement of the control lever is not accompanied by any noticeable jerking due to suddenly increased acceleration of the car.

Some tests carried out with one of these cars under the author's observation showed that the energy consumption compared favourably with that obtained with the more usual designs, and that the road speeds were satisfactory

The following particulars are of interest.—

Weight of Carriage—On front wheels, ...	1,889 lbs
On back wheels, ..	1,696 lbs
Total, ...	3,585 lbs
Weight of (4) passengers, . .	595 lbs
Total weight,	1 87 ton
Battery capacity 137 5 ampere-hours, or	11,200 watt-hours
Distance run,	50 miles
Average speed,	13 miles per hour
Energy consumption—per ton mile, .	120 watt-hours

Route followed—London to Brighton *via* Croydon, Redhill, and Handcross.

When running at about twelve to fourteen miles per hour, on the average level road, the amperes would, for example, be 35, and volts 85, or about 4 E.H P at the motor

The full battery voltage is always used, and as speed control is effected by regulation of the small shunt current instead of the main current, difficulties arising from burning of controller contacts do not occur

Fig 1223A shows the arrangement of connections with the Védrine carriage. With the exception of the use of the series short circuiting switch, the diagram is self-explanatory. When starting the car this switch is open, and the series field coils are active. During normal running and when reversing, the switch is closed and the series coils are then short circuited. The reversing switch changes the direction of running the motor by changing the direction of flow of current through the shunt winding.

Some of the accumulator-propelled electric vehicles here referred to were exhibited at the Paris Motor Car Show (Salon d'Automobile, 1908), and others[1] were there shown possessing novel features and interesting differences of detail and method of control.

Fig 1223B shows the chassis of one of the new cars of the British Electro-

[1] See *The Electrical Review*, January 1908, p. 52 *et seq.*

mobile Company (Carl Oppermann Patent), and fig 1223C a longitudinal section of the motor and an end view from the commutator end with the cover plate removed. A single motor is hung from two parallel frame tubes, and it drives, through a Renold's silent chain, the differential countershaft carrying roller chain pinions at the outer ends The power is transmitted to the road wheels by side chains, and there is thus a two-stage reduction by chain gearing between the motor and the road wheels. The side chains run inside gear-cases, and they remain clean and well lubricated The side chain pinions are made of fibre in order to minimize the noise of running gear as far as possible. The objections to the use of chains do not apply when, as in this instance, the chains are used under the usual conditions of use of machine-cut gearing running inside oil-tight cases There are, moreover, advantages attaching to the use of chains which, if appreciated, should lead to their more frequent use At present the Oppermann electric car is the sole representative of the chain-driven type suitable for use as an electrically propelled town carriage

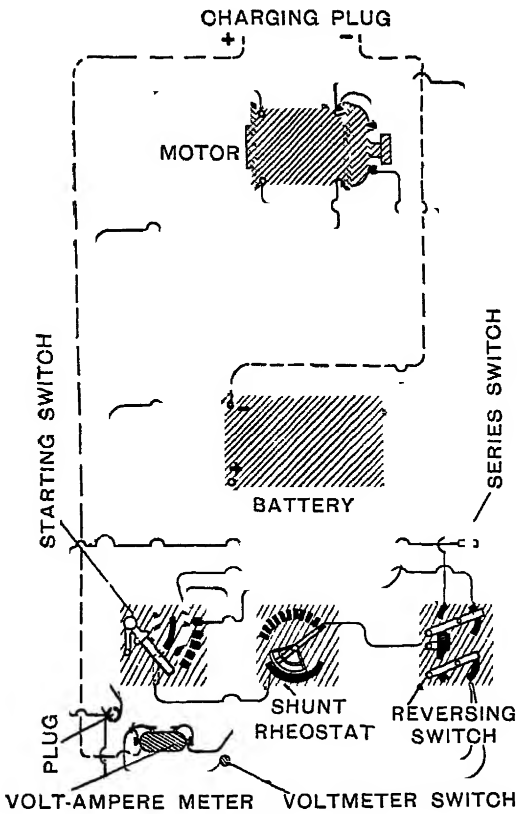

Fig 1223 A.—The Védrine Electric Carriage

The general disposition of weight in the car may be understood from inspection of fig 1223 B

The battery is supported from transverse frame members nearer the front than the back axle, and the motor is a little to the front of the back axle. When allowance is made for the load of the carriage body and the passengers, it becomes evident that there is nearly uniform distribution of weight on the wheels

There are 44 cells of the pasted type in the battery, the weight of each cell in its ebonite container being 24 lbs. The total weight of the battery and the carrying box is 10 cwt, and the overall dimensions of the box are: length 40½ inches, width 27½ inches, and depth 12½ inches At a 4-hours' discharge rate the battery capacity is 150 ampere-hours. The energy consumption varies from 120 to 130 watt-hours per ton mile, according to the route traversed and the condition of the surface. On

a level road, and when running at 14 miles per hour, the current required is about 30 amperes at 88 volts The dimensions and data relating to the complete battery are of interest as indicating the weight and the volume required per horse-power of stored energy.

The motor (fig 1223 C) is rated at 8 horse-power, and is of the 4-pole series-wound type The poles are laminated, and, as shown in the end view, every alternate plate has the pole tips or horns cut away at A, B, so as to leave a fringed area at the entering, and leaving edges of less average magnetic density than when the solid pole shoe is used. With less abrupt

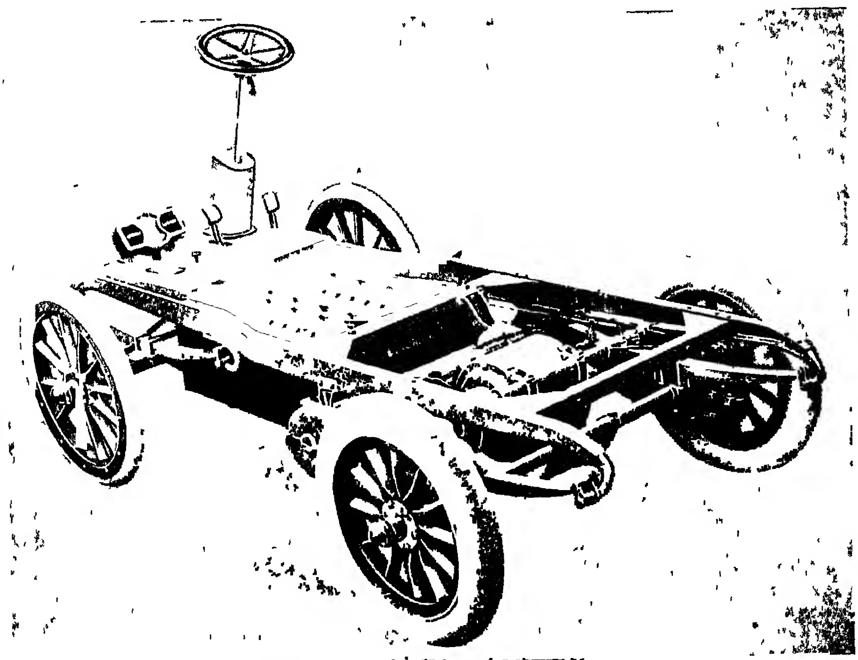

Fig 1223 B —The British Electromobile Carriage, 1908

change from the positions of maximum and minimum field-strength, it is claimed that no sparking occurs at the commutator.

The brush gear consists of 2 arms secured to a quadrant plate and set at 90°, each arm carrying 2 carbon brushes of the plunger type, or of the form in which the carbon block slides within a guide-box. The end plate of the motor is formed with a registering ring H, on which the quadrant plate is centred and fixed after adjustment to the position of no sparking. The armature spindle runs in a plain bearing at the commutator end, where there is no pull, and in a double-row ball-bearing at the other end, on which the chain pinion D and the brake drum E are fixed The motor is an interesting example of the modern light-weight, efficient, automobile motor.

The controller is situated at the base of the steering column, and it is arranged for the following positions and speeds.

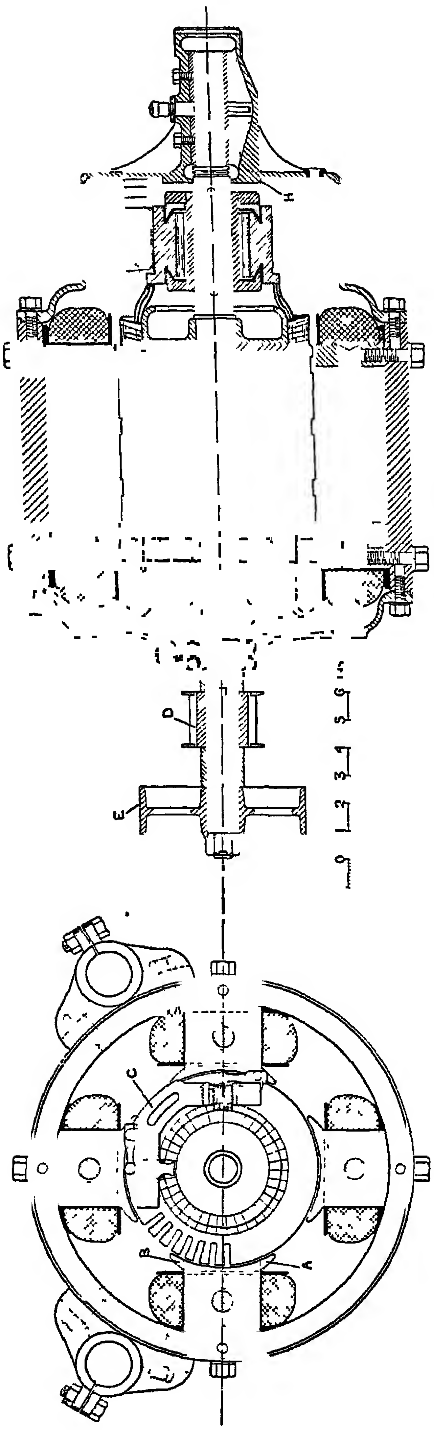

Fig 1223C —The British Electromobile Co 8 H P Motor, 1908

1 Battery in two parallels, giving current at 44 volts, with resistance in motor circuit Speed 4 miles per hour.

2 Battery in two parallels, but with no resistance in motor circuit. Speed 6 miles per hour

3 Battery in series, giving current at 88 volts, with resistance in motor circuit Speed 10 miles per hour

4 Battery in series, but with no resistance in motor circuit. Speed 14 miles per hour

For reversing, the positions 1 and 2 are employed with the direction of the armature current reversed.

The following dimensions are of interest as representing recent practice.—

Overall length,	10 feet 6 inches.
Wheel base,	6 feet 6 inches
Overall width,	5 feet 6 inches.
Height of chassis,	2 feet 2 inches
Width of frame,	3 feet 1 inch

The driving wheels are 32 inches diameter, and are fitted with pneumatic tyres 4¾ inches diameter.

Fig 1223D is an external view of one of the accumulator-propelled omnibuses of the London Electrobus Company The outline elevation and plan of the chassis (fig 1223E) represents the general arrangement of the machinery of the third and latest type put into service There are now 14 omnibuses in regular service, most of them of the type here illustrated, but two or three are of the bevel-gear driven live axle type, with one double-commutator motor.

Although of large size and weight as compared with the electric carriages here described,

they are nevertheless similar in type, and their performance may be directly compared with that obtained with the smaller vehicle As may be seen from fig 1223 E, the battery crate A is hung nearly from the centre of the frame from suitably spaced cross members. The bolts which support the load of 30 or 38 cwt. of battery and crate are provided with spring catches to guard as far as possible against the possibility of withdrawal of the bolts due to vibration; but they may be quickly withdrawn when the weight of the battery is transferred to the lift

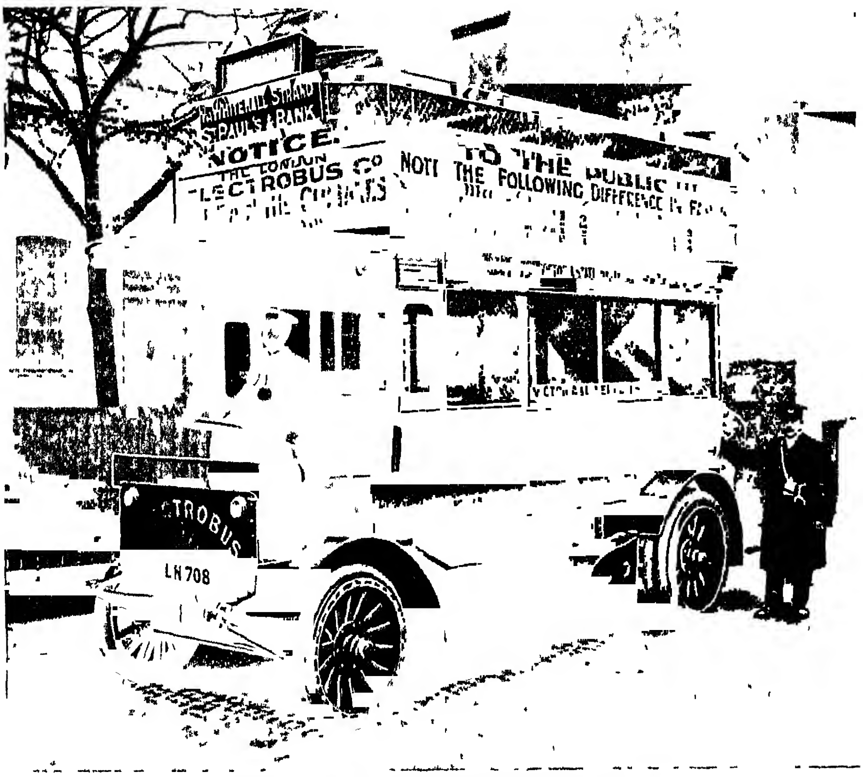

Fig. 1223 D —The London Electrobus, 1908 type, 34 passengers

platform during the operation of removing the discharged battery and replacing it by another freshly charged. At the omnibus depot there are conveniently arranged trolley ways and traverser tracks, by means of which the batteries may be quickly removed and replaced, and taken to or from the battery inspection and charging bays. The operation of removing and replacing the battery of one of these omnibuses does not usually occupy more than five minutes, and with a sufficient number of batteries the daily loss of time in changing need not be great. The omnibuses may be kept regularly in service with only such delays as are unavoidable and necessary for examination, adjustment, repair or renewal of other parts of the vehicle. The motors B are of the 6-pole series-wound slotted drum armature type, and they are adjustably hung from

the cross tube H. By means of the suspension screws J, the motors may be raised or lowered about the centre of H, in order to adjust the tension of the Renolds silent driving chains, which transmit power from the motors to the divided countershaft C. The same form of chain is used for transmission from the countershafts to the road wheels The gearing is thus of simple form, and the use of two motors makes it unnecessary to use differential gear, and the series parallel control may be used with the battery always coupled in series.

The controller is beneath the driver's seat at D, and it provides for four

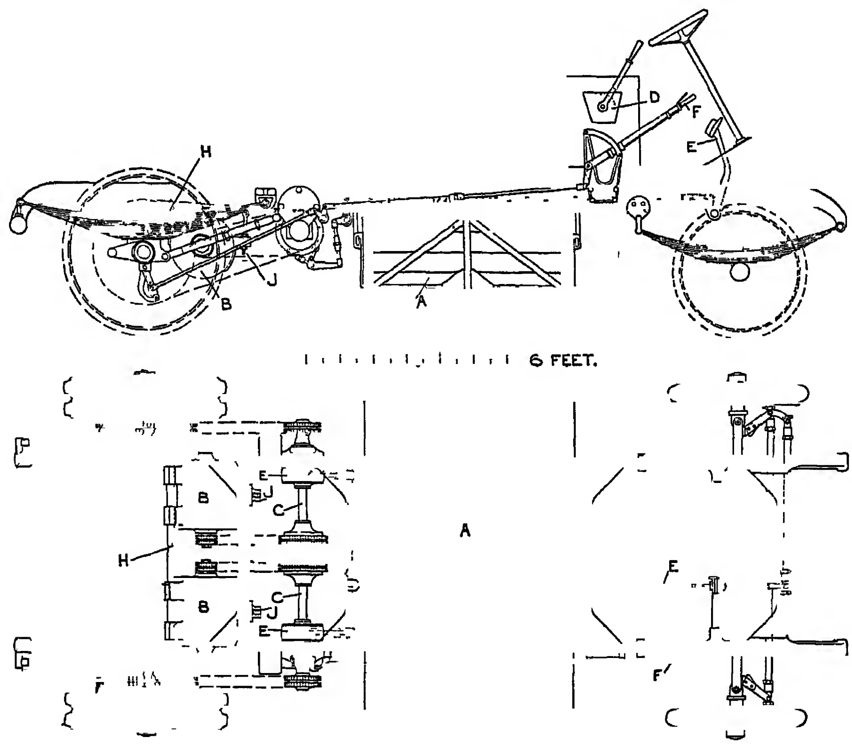

Fig 1223E —The London Electrobus, Two-Motor, Chain-driven Type

forward speeds and one speed for reversing. The usual series parallel combinations of armature and field windings are used, and on some of the omnibuses provided with five forward speeds, resistance is also used Electric braking is avoided, both the foot brake E and the side lever brake F being of the usual friction type, the one acting upon drums E on the countershaft C, and the other upon drums on the road wheels

The batteries used are rated at 500 ampere-hours capacity, and are of both the pasted and the Planté forms. The former, as made by the Tudor Company, weigh 30 cwt, and the latter, as made by the American Gould Company, weigh 38 cwt. Each battery consists of 48 cells On the Victoria to Liverpool Street route of four miles, three and sometimes four double journeys are made before it is necessary to change batteries

The weight of the omnibus with accumulators and in running order is 5¼ tons

The omnibuses have proved themselves capable of satisfying the conditions of London service, and they are, as might be expected, quieter in running than the ordinary petrol-propelled omnibus The slower speed at which they are run and the comparative ease of control both assist profitable running. It has yet to be demonstrated that heavy accumulator-propelled vehicles can continue to be run profitably as public service omnibuses, and much depends upon continuance of contracts now entered into for the supply and maintenance of the batteries at a cost to the Electrobus Company of *2d.* per mile

With the existing arrangements, current at from *1d* to 1¼*d* per unit is taken from the supply companies' mains and is reduced in voltage in motor generators There are thus losses in conversion and in transmission to and from the batteries to be allowed for in estimating the cost of the energy supplied to the omnibus motors The loss due to supply through the motor generators is avoidable, and cannot be regarded as expenditure incidental to this system of traction.

It is interesting to find that the energy consumption with the omnibus is the same as with some of the smaller electric carriages, namely, 125 to 130 watt-hours per ton mile

The Electric Vehicle Company, Limited, who supplied the electrobuses for London, are also the makers of light and heavy accumulator-propelled vehicles for passenger and goods transport The existence of this company suggests confidence in the possibility of economical transport by these means, but it is well to remember that, although such vehicles have been satisfactorily employed for some years in America, it is questionable whether the experience there gained, with other forms of automobile, enables a comparison of the working costs to be accepted as applicable to this and other countries. The accumulator-propelled vehicle is reliable, but the conditions of service, having been carefully predetermined, must be rigidly adhered to if economical success is to be approached

There have been many attempts to combine the advantages of the internal-combustion engine as a prime mover with the convenience of control and freedom from mechanical disadvantages of electrical transmission of power. Vehicles employing this mixed system are commonly termed petrol electric automobiles The systems employed vary considerably, and the difference between the accumulator-propelled type and those employing either a petrol engine, accumulators and electrical transmission machinery, or a petrol engine with electrical transmission machinery only, has become less marked. It is therefore desirable to call attention to the different classes in order that it may be realized that, although electrical machinery is employed, few of these petrol electric automobiles can be regarded as electrically propelled.

The Fischer combination system employed a petrol engine direct coupled to a continuous-current shunt-wound generator. Accumulators were also carried, and were used in parallel with the generator. When maximum power was required, current was supplied from the generator and the

accumulators to the series-wound motors which drove the vehicle. When little power was required, as for level running at moderate speed, the generator supplied current to the motors, and the surplus energy went to the battery, if its voltage had been reduced after discharge below its normal voltage and that of the generator. Under all circumstances power was transmitted electrically, and the combination system provided for electrical generation, storage, and transmission of energy The vehicle was heavy, and its efficiency low as measured by petrol consumption of the engine

The "Automixte" (system Henri Pieper) differs from the above in that a generator, which may also be a motor, is direct coupled to the engine A battery is carried of light weight, relatively low capacity, and with a high permissible rate of charge and discharge. The battery may either receive a charging current from the dynamotor when running as a generator, or it may supply current to it when running as a motor. A magnetic clutch is used between the dynamotor and the mechanical transmission gearing to the road wheels, and the vehicle is only driven when this clutch is engaged It is evident, therefore, that the whole or a part of the engine power is directly transmitted without electrical transmission, and additional power may be delivered from the battery to the dynamotor to assist the engine, or a part of the engine power may be used for driving the car, and the remainder stored in the battery, the dynamotor then acting as a generator. Fig. 1223F shows the arrangement of the principal parts.

The change of function of the dynamotor occurs automatically, and depends primarily upon the road speed of the car. If, however, the battery has undergone nearly complete discharge, after continuous hill-climbing, then it will receive a charging current at lower road speeds than when it is only slightly discharged, and when its reduction of voltage is also small.

With the Automixte as with the Fischer vehicle the increased torque is obtained by electrically transmitted stored energy, but with the former a part of the power is transmitted without loss in conversion, and the average efficiency of the combination is higher The equivalent of the mechanical advantage obtained with the commonly employed forms of change speed gearing has to be obtained by utilizing stored electrical energy, and not by change of character of the electrical energy supplied

A third system or class, which has been recently tried by several makers, has been the subject of experiment for many years Passing over the early types, among which may be mentioned the German Dynamobile, the motor omnibus and commercial vehicle designs of the British Thomson Houston Company, Messrs. Greenwood & Batley, and the Hallford-Stevens, may be included in one class, although there are important differences of detail

In these vehicles the petrol engine drives the generator, and it supplies current to the series-wound motor, or motors which deliver the power to the road wheels. The equivalent of the change speed gear effect is gained by change of character of the generator output The generators are

constant watt dynamos, capable, at constant speed, of giving large current at low voltage, or small current at high voltage. The hill-climbing capability of these vehicles is controlled by the range of variation of output of the generator, and the limit of torque increase, with decrease of speed of rotation, obtainable with series-wound motors, depends upon the amount of this variation

One important point should not be lost sight of in considering the results obtainable, namely, that the power is limited to that of the engine, and the starting efforts that are to be got with series-wound motors, with unlimited power supply, cannot be obtained when there is either no increase of power, or only that represented by momentary increase

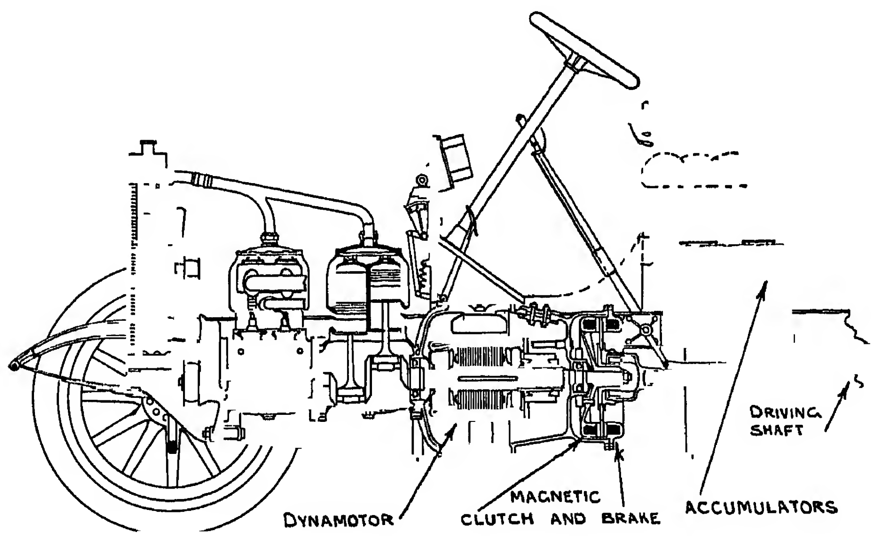

Fig 1223 F —The Automixte, forward part of Car

of engine speed and the utilization of the stored energy in moving masses

In the Hart-Durtnall petrol electric omnibus an interesting attempt has been made to use polyphase alternating-current machinery for transmission of the power. An independent continuous-current dynamo is used for field excitation of the generator and for excitation of a magnetic clutch. At low speeds the power is transmitted electrically from the three-phase generator to the three-phase induction motor, which is provided with two sets of pole windings in order to obtain two speeds of rotation without using resistance in circuit. There is necessarily considerable departure from these speeds when accelerating and when stopping.

At speeds above 9 or 10 miles per hour the engine drives direct through the magnetic clutch and mechanical driving gear, the electrical plant, with the exception of the exciter machine, running idly.

All these systems possess the leading advantages of ease of control and quietness of running, and vehicles of, for instance, the second and third

classes will, without doubt, be used when it is found that they are particularly suitable for use where road traffic necessitates frequent starting, stopping, and speed variation.

CHAPTER II

ELECTRIC BOATS

Electricity was applied to the driving of boats in the days before dynamos, or even the magneto-electric machines, were invented. In these days the motive power was obtained from primary batteries, and the motors were of the elementary type which depended for their operation on the attraction of iron armatures by electromagnets For instance, in 1838 Professor Jacobi equipped a boat which would hold twelve persons. In the course of his experiments he first used Daniell cells to generate the electricity required, and afterwards obtained more successful results with Grove cells. He actually obtained a speed of from 1½ up to 2½ miles an hour by these means While these early experiments indicated what could be done, it was not until accumulators had been invented that electric launches, both for river and marine traffic, entered the range of commercial possibilities

The electric boats may be classified in many ways, but perhaps the best method of dividing them into classes deals with the supply of electricity to the motor. In this way the first and largest class comprises those boats which depend entirely on electrical energy stored in accumulators for their propulsion In the next class, which includes many of the submarine boats with which the various naval authorities are now experimenting, the accumulators are charged by means of steam or gasoline engines on the boat itself These submarine torpedo boats are hence only partially electric, as they only use electric energy for driving when a submarine journey has to be made At other times the boats are propelled by the gasoline or steam engines. The third class comprises those boats to which the electrical energy for driving the motor is conveyed by means of conductors from generating stations In this class one would expect to find electric tug-boats on canals; but while these have been tried, they have almost all been superseded by the use of tractors running on the tow-paths by the side of the canal, and taking current from overhead wires as tram-cars do Naturally any boat which depends for its propulsion on a moving connection with wires on the shore can only have a limited course. Such boats have been used, however, on a few lakes attached to places of amusement.

There is on record, however, one instance from the United States in which such a boat equipped with a double trolley did great service. It was in the early part of 1898 that an extensive work had to be carried out in a large sewer in Worcester, U. S. A. The sewer was 18 feet wide by 13 feet high, and in order to divide the storm water

from the sewage it was decided to construct a small sewer 6 feet wide along some 4000 feet of the larger sewer to take the normal flow. The work was carried out by means of coffer-dams The electrical equipment consisted of a dynamo and engine placed near a main shaft at about the centre of the sewer. From this dynamo two overhead trolley wires, supported on insulators from the arch of the sewer, were supplied These wires served as the lead and return conductors respectively, and were also employed to light the sewer All the materials required for the constructional work were taken down the shaft and placed into scows The electrical boat was of the catamaran type, 22 feet long and 5 feet wide. It had a small paddle-box constructed in the middle in such a way as to prevent the paddles splashing up the sewage The paddle-wheel was driven by a 2½-horse-power motor, and this was found to be quite sufficient for hauling six of the loaded scows. A normal day's work of this electric tug-boat was the conveyance of 12,000 bricks, 50 barrels of cement, and 100 barrels of sand It also was equipped with a 14-horse-power motor, coupled to a pump, which was used for emptying the coffer-dam of water The equipment in this case was designed by Mr. Harrison P. Eddy, and is an example of the economic use of electric boats for a special commercial purpose

To return now to the first class of electric boats, in which accumulators only are used A great deal of pioneering work was carried out by the late Mr. M Immisch on the Thames, which was a good field for this experimenting on account of the wealthy population living on its banks The outcome of Mr Immisch's efforts is the Immisch Electric Launch Co, which owns a large fleet of electric boats running up and down the Thames, and a number of charging stations at which the same can be stored and recharged when their accumulators need attention These launches vary in length from 20 up to 65 feet, and have a varying capacity from four to eighty persons The range in the horse-power of the motors is from 1½ up to 12 horse-power In the earlier days all these motors were of the Immisch type, in four standard sizes, but many other makes are now employed. Unfortunately the electromotive forces required from the accumulators was usually increased with the size of the boat. In consequence, voltages of 65, 95, and 120 volts are to be found for the motors and batteries on the same fleet. The company have used mostly the accumulators of the Electrical Power Storage Company's make of the types T 23, B 15, and E 19 They have also employed largely the Epstein C.7 cells. Apparently the original idea was to vary the voltage on the motors with the size of the launch, and to keep the current practically constant on all the types The capacity of the battery is usually designed to give with certainty a run of 30 miles on one charge. In this case half the distance is taken to be up stream and one-half down.

The average speed of these launches is about 6 miles per hour, but in certain cases considerably higher speed has been arranged for. In these special cases it is frequently the custom to put the accumulators into two parallel circuits when regulating for speed. In the illustra-

tion (fig. 1224) one of these launches is shown, which is capable of giving a speed of 8 miles per hour In this instance the electromotive force of the accumulators is 120 volts and their normal discharge rate 40 amperes. The speed of the motor is 600 revolutions The motor is of the Immisch type, with a 7-inch diameter armature 14 inches long. The armature is drum wound, and the bearings are provided

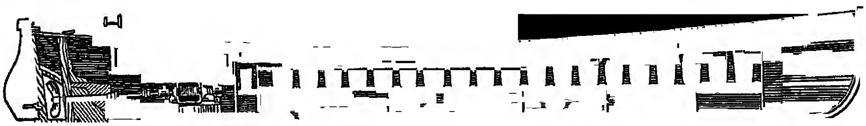

Fig 1224 —Section of Immisch Electric Launch

with a ball-bearing thrust to reduce friction. The current is supplied to the commutator by means of carbon brushes The above illustration (fig 1224) gives a section of one of the Immisch electric launches, and shows the position of the cells under the seats The motor is placed under the floor, so that practically the whole of the launch is available for seating accommodation In this instance the boat is shown steered by a tiller, but in the larger launches the steering gear is brought forward, so that the attendant has an unobstructed

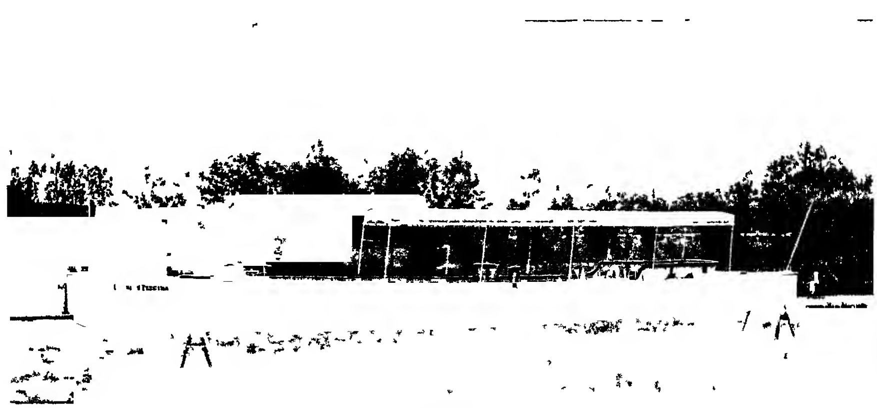

Fig 1225 —Electric Launch

view of the river before him This leaves the back of the launch quite free for the pleasure party. As a rule the control of the motor is effected by a switch with five positions, which allows the motor to be driven both at half speed and full speed ahead, at half speed and full speed astern. In the remaining position the motor is disconnected altogether. In a certain number of recently built launches a series parallel control is used for connecting up the accumulators in different groups It is interesting to know that the average draught of the launches forming this fleet is under 2 feet 6 inches Besides the charging stations on shore mentioned above, the company owns two floating stations, which are equipped with steam-driven dynamos The advantage of this is that charging stations can be

moved up and down the river to meet special requirements at regatta times

Before proceeding to describe launches on the Thames by other makers, it will be of interest to note some experiments made in 1888 on one of these Immisch launches by Professor George Forbes. This information is abstracted from a communication on the subject read before the British Association for the Promotion of Science at Newcastle-on-Tyne. At that date it seems there were already four or five charging stations on the Thames, so that the electric boats could be used conveniently over a considerable distance. The launch experimented on was called the *Delta*, and was 33 feet in length, 6 feet in beam, and drew 18 inches of water at the stern. She was equipped with forty-five accumulators, with a total weight of 2520 lbs She was steered by a wheel in front, and had a type of controller with three handles which at the present day is obsolete. The motor was coupled direct to the propeller, and ran at 720 revolutions per minute for full speed and 510 revolutions at half speed The full speed was between 5 and 6 miles per hour, from which it will be gathered that the average speed of electric launches on the Thames has not been greatly increased since 1888 The launch would hold twenty passengers in comfort, and Professor Forbes comments on the greater accommodation than there would have been in a similar launch equipped with a steam-engine and boiler In the paper a full day's trial is described, in which a journey was made from Bray to Hambleton Lock and back. The average speed up-stream was 5 3 miles per hour, and the average speed down-stream 5.9 miles per hour. After the double journey the stern of the launch was attached to a spring-balance connected by a rod with the shore. Professor Forbes states that "the pull at full speed was then measured, and found to be 97 lbs, which, although it does not accurately represent the pull when the launch is in movement, does so with sufficiently close approximation This gives 1.44 horse-power, or 1074 watts, including electrical losses, slip, and all friction" This figure is arrived at by multiplying the draw-bar pull and the average speed "The average pressure at the motor terminals during the run was 78 volts, and the average current 23 amperes, which gives 1794 watts expenditure. This gives a total efficiency, including all these losses of slip, friction, the end-thrust of the propeller, and the electrical losses in the motor, at 60 per cent, which was a good performance for one of the first types of electric launches."

Professor Forbes in his paper, predicting the rapid extinction of the steam launch on the river, advocated that energy for storing in the accumulators of the electric launches might be obtained, by the permission of the Thames Conservancy and mill-owners, from the waste water going over the weirs.

Another firm which has done good work in the development of the electric-launch business on the Thames and elsewhere is the Thames Valley Launch Company of Weybridge. In the carrying of accumulators there can be little new to do, but this firm have made some

improvements both in steering gear and in the propeller which are worthy of special attention. With respect to the propeller, this is designed with feathering blades, which can be controlled by the steering handle in the way indicated in the illustrations. The advantage is that the armature of the motor is not only always running in the one direction, but is also running at approximately the same speed, while the speed of the boat is varied by altering the pitch of the propeller. This is provided with reversible blades, fixed, as shown, in a sleeve on the main shaft. When these blades are at right angles to the shaft the propeller will revolve without driving the boat at all With this reversible-bladed propeller (fig. 1226) there is also connected the steering gear, so that one handle serves both to control the speed and direction of the boat. The way this is done by means of a lever is shown in the illustration herewith (figs. 1227 and 1228). The lever A is attached to the steering gear of the boat, so that by moving radially round the shaft in one direction or the other the ruddei is moved. It will be seen that this lever turns upon a pivot G upon the lower part of the frame H, which itself is supported in bearings which carry the propeller shaft. The quadrant P is a guide for the lever in the usual way, there being a spring catch R and a notch S for the central position of the lever, the movement of which gives the different positions of the blades for driving either ahead or astern. A supplementary and parallel quadrant T is carried by the frame H, and has a curve in its face connected with

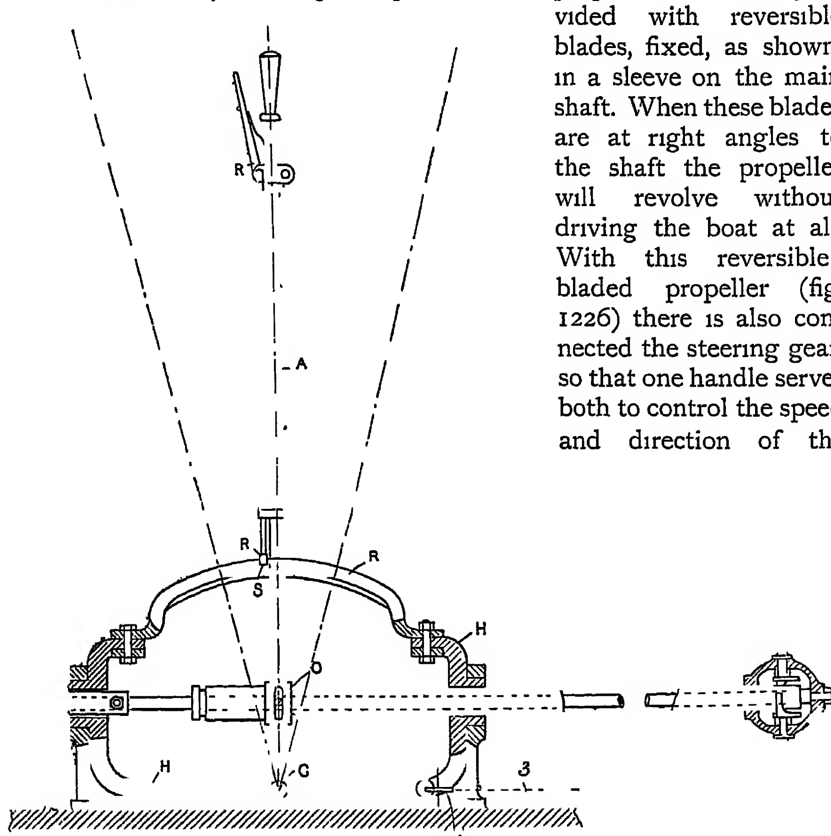

Fig 1226

the electrical circuit. The lever A is connected with the bracket U, in which is pivoted a lever V, at the other end of which is carried a small brush W, used to complete the electric circuit The spring X tends to keep the brush against the quadrant to clean the contacts When, however, the lever A is in its central position, the catch R is forced into its notch S, and a lateral projection Y forces down the inner end of this lever and breaks the circuit at the contact W. Ropes are attached to the frame H, which, after passing round pulleys as indicated in fig 1228, operate the tiller by the ropes It will be seen from this that with a single handle everything can be done for controlling an electric launch This apparatus is the invention of Mr. W. Rowland Edwards, the managing director of the above company This company has now eight charging stations in various parts of the river at which electrical energy can be obtained for electric launches. They charge to all boats made by them 8*d* per unit, which they state allows a small boat to be run for 25 miles on one charge at a cost of a little over 2*d* per mile

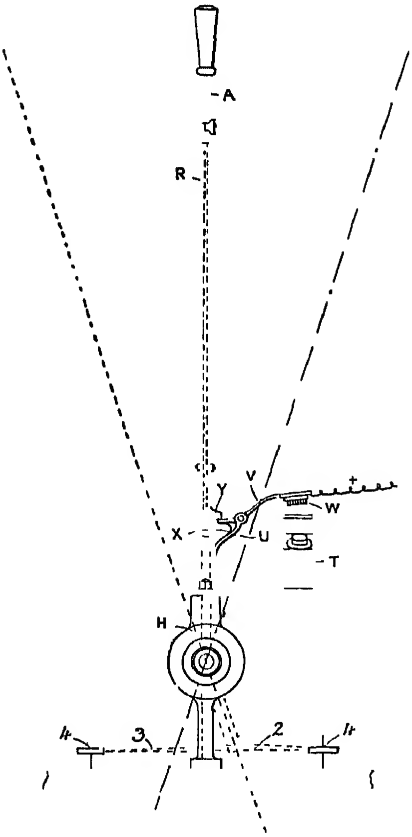

Fig 1227

The success of electric launches on the Thames has been attained in spite of high rates of charge for electrical energy Until the past year or

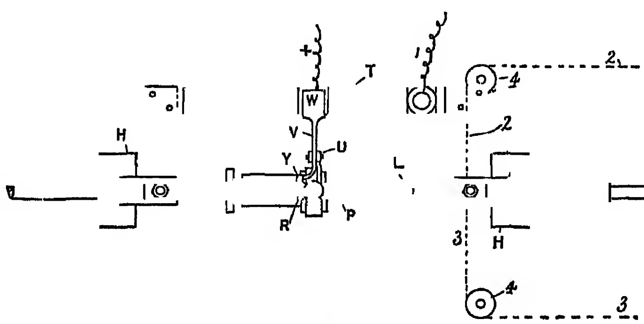

Fig. 1228

two it has been quite usual for the owner of an electric launch to have to pay half a crown per Board of Trade unit for recharging his cells. Even

when the electricity has been obtained from the main of a corporation, or an electrical company supplying a town on the river, the charge has not been much less. The reasons for the high scale are two: the first being that the demand is limited, and the other that no standard voltage is in use on these electric launches. In consequence the boat-builder who undertakes to retail electricity taken from the public mains to the owners of launches has either to have an expensive equipment of motor generators for altering the voltage, or else to use resistances in series with the accumulators. When this latter course is adopted there is a great waste of energy entailed There are now over twenty charging stations in the distance of 100 miles between Oxford and Kingston.

The Thames has by no means the monopoly of electric launches in this country, as a considerable number of our corporations have purchased electric boats for use on the ornamental waters in their parks. In the Cumberland and Irish lake districts also a goodly number of electric launches are to be found, and it is of interest to know that the progress made by English builders has resulted in foreign orders. For instance, a considerable number of boats have been built for use in Venice

The sea-going electric launch has been somewhat slower in development In the end of 1887 the French Admiralty experimented at Havre on the use of accumulators and an electric motor for driving a cutter 29 feet long for harbour work in and around the port. The accumulators used had a capacity calculated to give normally a six hours' run at 6 knots, 132 cells were employed, and by means of a commutator the cells could be arranged in various groups so as to control the voltage and hence the speed. A computation was then made of the weight of accumulators, the motor and the controlling commutator amounted to 6380 lbs, whereas the total weight which the same cutter would have to carry, if equipped with a steam-engine, would be 6280 lbs In this weight was included the engine, the boiler, and sufficient coal and water for a four hours' run It is not on record how long this electric cutter was at work The Russian navy have also one or two electric sea-going launches, which were built in this country. One of these, constructed by the Vril Launches Co in 1898, was 32 feet long, 8 feet in beam, and 3 feet 8 inches draught. It was equipped with two 5-horse-power motors and a wheel controller. Forty-two Faure-King accumulators were used to drive it, and were guaranteed to maintain a speed of 7 knots for four hours, or 4½ knots for ten hours In this case a series parallel controller, such as is used on a tram-car, was employed, at half speed the motors were worked in series, and they were connected in parallel for full speed Intermediate speeds could be obtained exactly in the same way as in tramway work, both by the insertion of resistance and by variations in the amount of current allowed to go through the series windings of the motors. This system of controller is much preferable to one in which the grouping of the cells is varied This is so, because whenever two series of cells are connected in parallel it is exceedingly difficult to ensure an equal treatment for the cells in each series. Any fault in a single accumulator is then likely to cause considerable trouble and to damage the accumulators in the parallel circuit.

The heaviest boats in which electricity has yet been used are those connected with submarine torpedo work The competition of recent years between France, England, and the United States has led to the building of a large number of these submarines The French naval authorities have laid particular stress on the value of submarine boats for harbour defence, and have induced their government to build a large number Thus, at the end of 1902 there were in the French navy no less than thirty-five submarine vessels, while an equal number were either in course of construction or on order. In the United States, although a large amount of experimental work has been done, there has been no building of such a considerable number of submarine torpedo-boats. The English navy now contains five submarines, which come under the class of boats which are electric only when diving To refer briefly to a few submarines in the French navy first, those of the *Français* and *Algerian* class have a tonnage of 146, while the *Farfadet*, *Korrigan*, *Gnome*, and *Lutin* have a displacement of 184 tons

The above are electric boats only, and depend on having their accumulators periodically charged either from the machinery on board ship or from a land installation They may therefore be looked upon as serviceable for port defence only. The submarines *Morse*, *Narval*, *Espadon*, *Silure*, *Siren*, and *Triton* are of the type in which engines can be used when the submarine is cruising at the water's surface, and the change to electrical driving is made when the boat wishes to go under water Both gasoline-engines and steam-engines are under trial on some of these latter submarines

The *Holland* submarine boat, developed by Mr Holland in the United States, has been adopted by the British government as the type to which to adhere in the construction of the five submarines now being experimented with The original *Holland* was 35 feet long, and is owned by the United States government. She has proved herself capable of such perfect control in the vertical plane that she may be kept moving within a few inches of any desired depth The latest type of the *Holland* boat made for the United States has the following dimensions, and six of these vessels are being constructed The length is 63 feet 4 inches, the diameter 11 feet 9 inches, and the submerged displacement 123 tons The main engine is of the four-cylinder single-acting gasoline type working on the Otto cycle at 360 revolutions, which will develop 160 horse-power When working as a submerged electric boat, an electric motor running at 800 revolutions is employed and a speed of 7 knots is obtained. The storage-batteries are capable of supplying 70 horse-power for four hours, and these are charged from the main engine when the vessel is running on the surface The accumulators weigh about 22 tons The motor is connected to the main shaft by means of gearings, so that the change from one system of propulsion to another can be promptly made

The construction of submarine boats in this country has been carried out by Messrs. Vickers, Sons, & Maxim, and the principal dimensions of some of these are practically the same as those given above for the *Holland* type in the United States navy. The section (fig. 1229) reproduced below

gives an idea of the general arrangement of the machinery in this *Holland* type of submarine In this drawing can be seen the gasoline-engine E, which drives by gearing the main propeller shaft when the boat is at the surface. It is also connected by gearing to the dynamo marked D, which can be used to charge the accumulators while the boat is cruising at low speeds at the surface By means of the same gearing the dynamo acting as a motor drives the propeller when the boat has to undertake a submarine journey. The accumulators are placed, as will be seen, in the centre of the boat over the main ballast tanks, which are used to regulate

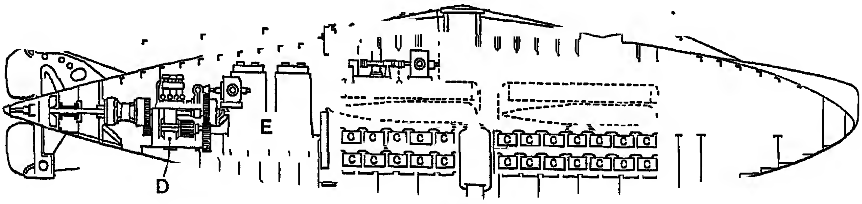

Fig 1229

the buoyancy of the vessel and also its horizontal equilibrium when below the water. A number of air flasks provide air for the crew, apart from the reservoir of compressed air used to discharge the torpedo An ingenious compensating tank is filled with water immediately a torpedo has been discharged, so that the equilibrium of the boat shall not be upset The boats have a radius of action at the surface of about 400 nautical miles, with the 850 gallons of gasoline which they carry. The storage-batteries on the one charge have a capacity for a run of 28 nautical miles on a four-hours' submersion. The largest vessel of this type in the British navy is 150 feet long The radius of action at the surface has been increased to 500 miles, and a distance of 90 miles can be run submerged

Since the foregoing was written great extensions in the construction and use of submarine boats have taken place in the British navy, but the electrical features do not call for further reference.

9. Electric Traction on Railways

CHAPTER I

INTRODUCTORY

This problem is at the present moment occupying the attention of most of our railway companies, and there seems little reason to doubt that in the near future electric traction will play a considerable part in the operating of railway systems How far it will be possible for electric traction to entirely replace steam is too intricate a question to be examined here, as the conditions which will govern the introduction of electricity on railways, either for their urban, suburban, or main-line passenger traffic, as well as the question of handling freight traffic, vary in every case, and no general rule can at present be laid down as regards the advisability of adopting electrification in each particular case Generally speaking, however, as far as this country at least is concerned, owing to financial and other difficulties, the question of operating our long-distance lines electrically is as yet too far off to demand minute consideration

The chief problem before the country to-day is the electrification of the suburban lines in our great cities, and of those interurban lines, connecting cities not too far apart, on which a very frequent train service exists This subject demands immediate attention, and should be taken in hand at once by all the large railway companies.

To those who are acquainted with the actual results which have been obtained by the introduction of electric traction, it seems absurd that it should be necessary to reiterate so often that for handling heavy passenger traffic with frequent stops, electric traction has such enormous advantages as to be practically essential for a good urban service.

As regards the use of electric traction on railways, the cases to be considered may be classified under three headings:—

(1) Lines catering only for urban and suburban traffic, such as the Metropolitan District, the Metropolitan, and its affiliated lines, having no main-line traffic or express long-distance service

(2) An express service between two neighbouring towns, or interurban lines, such as the proposed Manchester and Liverpool and London and Brighton schemes, in which only one class of service on a comparatively small system has to be considered.

(3) A mixed system in which urban, interurban, and main-line trains are all owned and operated by one company from the same terminals.

This is the case of all our railway companies, and the most difficult one to solve, owing to lack of terminal facilities and heavy capitalization

In the last-mentioned case there are instances in which either an interurban, urban, or suburban line can be considered for all practical purposes as entirely separate from the rest of the system, in which case it may be quite easy to introduce electric traction.

When the question of electrification of railways has to be considered, not only do very minute calculations have to be made as to the probable cost of the installation and working of it, but also as to the effect which the electrification may have in developing new districts and creating a new traffic. It is quite possible that in many cases, owing to the additional capital expenditure involved, the total working expenses, including interest on capital and sinking fund, may be slightly higher than the present cost of working by steam; but against this must be put the additional facilities which will be offered to the travelling public, and the increase of traffic which invariably follows electrification

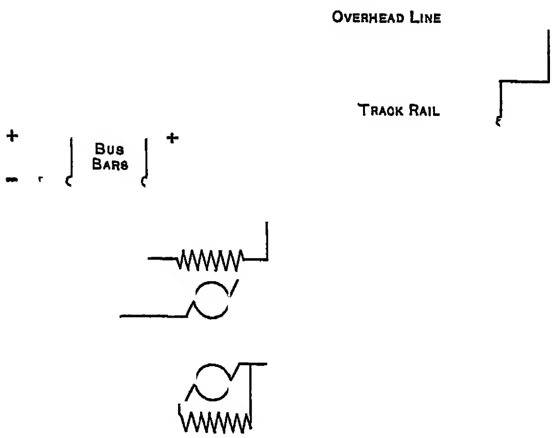

Fig 1230 —Negative-Booster Connections

Traction Systems.—There are four main systems now in general or exceptional use, and these may be classified as follows:—

(*a*) Continuous current is generated at a central station and transmitted without transformation to continuous-current motors on the cars.

(*b*) Polyphase currents are generated at high tension and transmitted to sub-stations, where they are transformed into continuous currents either by motor generators or by rotary converters, continuous-current traction-motors being used.

(*c*) Three-phase currents are generated at high tension and transformed to a lower working pressure by static transformers, situated in sub-stations or on the cars themselves. Three-phase traction-motors are used.

(*d*) Single-phase current at high pressure is supplied to the line, and used in single-phase motors on the train.

The first two methods are the best known, and have found a wide application. The first system is the simplest, so long as the distances to be served and the power to be supplied are not too great In the United Kingdom, where the Board of Trade prescribes that the drop in the rails shall not exceed 7 volts, it is rarely possible to use this method by itself when the ends of the lines to be fed are more than three miles

from the power-house, as the drop becomes too great. In such cases negative boosters have been employed with success. A negative booster generally consists of a generator directly connected to a shunt-wound motor. The armature is connected to the negative bus-bar at the station switch-board, and to the track at the place where the drop is to be reduced, as shown in fig 1230 The field is connected to the positive bus-bar on the switch-board and to the overhead line at the same place that the armature is connected to the track A rheostat in the field serves to regulate the amount of boosting necessary; otherwise the machine is self-adjusting Positive boosters are sometimes used to reduce the drop in the positive feeders, and act as continuous-current step-up transformers They are usually constructed with a double field and two armatures mounted on the same shaft or connected by a coupling, the motor armature driving that of the generator. This apparatus is self-regulating, as the main current passes through the generator field and armature in series with the line, so that as the load on the main circuit increases, the strength of the field of the booster is augmented, and the required additional pressure is furnished to the booster circuit These machines can be wound for any required increase in the voltage Fig 1231 shows the connections.

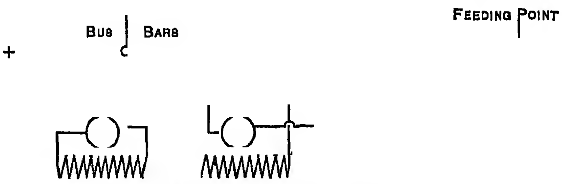

Fig 1231.—Positive-Booster Connections

Where the demand for current at a distance from the power-station is very variable, battery sub-stations have been employed with great advantage They may be used with great advantage at points distant from the power-station where sudden rushes of current are to be met with, the average current being comparatively low. The battery does away with the necessity for the abnormally large feeders which would otherwise be required. The South Side Elevated Railway of Chicago is a case in point. The connections of a sub-station on this line are shown in fig 1232 The power-house is situated somewhere about the centre of the system, and there are five feeders running each way, which are connected to the third rail at various points. At approximately half-way between the power-house and the ends of the line battery sub-stations have been installed, the batteries being connected up between one of the feeders and the track. The introduction of storage batteries was due to the fact that the high-schedule speed required, and the large number of trains in operation, caused the demand for current to be very heavy, and the variation in the load at the central station was considerable. The batteries have been found to have a very beneficial effect as equalizers, as can be seen

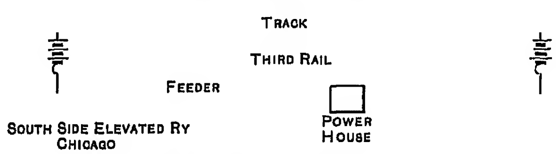

Fig 1232 —Battery Sub station Connections

by comparing the load diagrams shown in fig. 1233, giving the fluctuations both without and with the use of cells Their operation is entirely automatic, and no booster is used. Besides acting as equalizers, the batteries reduce the potential drop in the line, and to a certain extent help to carry peak loads.

The second system (*b*) is that which is now generally adopted for heavy service combined with large areas.

The transformation of the alternating currents into continuous currents can be done either by rotary converters or motor generators. The use of the latter is much favoured on the Continent, but in Great Britain and the United States of America rotary converters are more common.

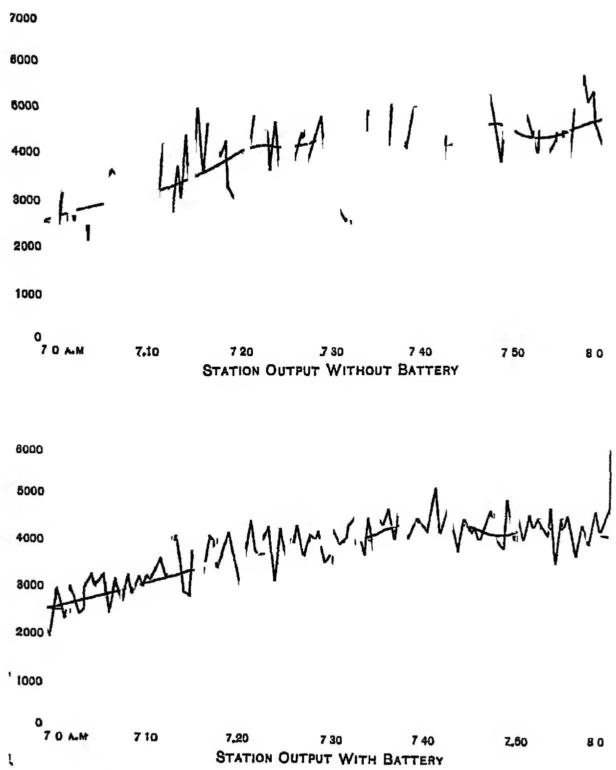

Fig 1233.—South Side Elevated Chicago Railway—Load Diagrams

With reasonable frequencies, say 25 cycles per second, or less, a rotary converter is always to be preferred With a motor generator, the combined efficiency between about quarter-load and 50 per cent overload varies between 78 6 and 91 per cent, whereas a rotary converter will give an efficiency, as shown by the curves, of from 80 to 96 per cent (see fig 1234). Also, a motor generator is more expensive in first cost, as it consists of two complete machines.

The subject of motor generators and rotary converters is of sufficient interest to warrant further investigation. There are three kinds of machines for converting alternating current into continuous current. These are:—

(*a*) Asynchronous or induction motor generators.
(*b*) Synchronous motor generators.
(*c*) Rotary converters.

In the first two cases the high-tension current from the generators is usually led directly into the alternating side of the machine; but

with rotaries, step-down transformers are required to lower the voltage, because of the fixed relation which exists between the continuous and alternating currents in the armature circuits.

This relationship has been shown elsewhere in this work and need not be touched upon here.

In America it is usual to employ a separate transformer for each phase, and in the case of three-phase systems they are usually connected up in Δ on both high- and low-pressure sides. This method has the advantage that the supply need not be interrupted if one transformer should from any cause be put out of service, as all three phases of the rotary will continue to receive three-phase current from the two remaining transformers If the transformers were star-connected, single-phase current would be supplied should one of them fail, and the rotary would have to be cut out immediately.

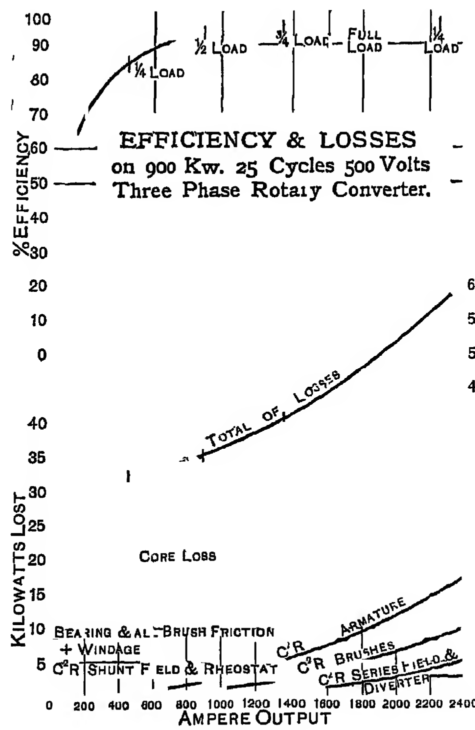

Fig 1234

In a rotary converter the motor and generator currents in the armature conductors overlap. The currents which the armature of a rotary converter receives into the motor end will generally be flowing *against* the electromotive forces induced internally by its rotation in the magnetic field, while the currents which it gives out will be flowing *with* these electromotive forces As one armature and set of windings serve both for the alternating currents which drive the motor and the continuous currents given out at the commutator, the hysteresis and eddy-current losses and thermal losses are less than those of either a continuous-current generator or a synchronous-current motor taken separately, and the armature reactions are practically neutralized. This last fact makes current collection at almost any load free from sparking, without shifting the brushes. In a motor generator the brushes on the commutator of the generator have to be set exactly as in an ordinary continuous-current generator, so as to avoid sparking.

The cross-section of the conductors in a rotary may be made very small for a given output; and a very large number may be used from the thermal stand-point, and also because of the absence of armature reactions. This permits both the flux per pole-piece and the cross-section

of the magnetic circuit to be small. The commutator must, however, be as large as for a direct-current generator of the same output.

Three-phase transformers can be connected up to supply six-phase rotaries, which are slightly more complicated than three-phase machines, but possess some distinct advantages, and are not any more expensive to build. For the same mean temperature of the armature coils the output of a six-phase converter is nearly half as great again as that of a three-phase machine, and the heating of the armature is also much more uniform. The heating is always greatest near the connections to the slip-rings

The regulation of the direct-current pressure in motor generators is done entirely on the generators, either automatically by compound winding, or by hand through field regulation. With rotaries, however, the pressure on either side is almost wholly independent of the strength of the field, and thus to regulate the direct-current pressure it is necessary to regulate the pressure delivered to the converter.

The impressed pressure can be altered by changing the ratio of transformation of the transformers, by means of a multiple-contact switch which allows the number of either the primary or secondary turns to be altered by hand The regulating switches for each set of transformers are interlocked so as to produce equal changes simultaneously in each unit. An induction regulator is, however, much better if hand regulation is required. The regulator consists of an iron core in connection with a shunt and series winding in each phase, arranged so that the mutual induction between the two windings is altered by the movement of the core. The core being moved inwards, the pressure on the converter slip-rings is reduced because of the inductive action of the shunt winding. When the core is moved outward the series coils are less influenced by the shunt winding, and the pressure rises

Another method is for the rotaries to be compound, with choking coils inserted in the leads between the slip-rings and the secondary windings of the transformer.

In working with motor generators of the asynchronous type, it is important to keep them as fully loaded as possible, below three-quarters load the power factor of the motor is less than 90 per cent It is also important to watch the air-gap, which is made as small as possible so as to obtain a large power factor.

With motor generators the overload capacity is entirely dependent on the direct-current portion of the machine, and will approximate to 20 per cent for two hours. The overload capacity of rotaries is determined by the heating of the commutator, and may be reckoned as 40 per cent to 50 per cent for two hours

Trouble is sometimes experienced with rotaries hunting when running in parallel This is generally caused by uneven running on the part of the main generating engines, but it can be started in various ways quite independently of the engines Machines are said to "hunt" when, whilst running at synchronous speed as measured by revolutions per minute, their angular velocities during one revolution oscillate about the value corresponding to exact synchronism. These oscillations weaken and

distort the field flux of the converter; the machine is either acting as a generator or motor, and consequently shifts the diminished field flux to one or other of the pole-horns. The armature tries to follow the change in the field, and in doing so takes a large current in the reverse direction The field flux is, however, immediately distorted in the opposite direction by the change of current, and the armature again tries to correspond The swinging may thus eventually become so great as to put the machine out of step. The remedy is to prevent the distortion of the field as far as possible

The causes of hunting are various; if the form of the E.M F wave of the generators differs from that of the rotaries, hunting will in some cases follow. A strong armature reaction (or if the machine is much under-excited) will favour hunting more than if the field is strong, as distortion of the magnetic flux is more easily produced.

Damping coils will prevent the distortion of the field. These consist of copper strips which bridge the poles from horn to horn. The eddy currents in these strips, due to the large leading and lagging armature currents, produce a flux which opposes the distortion of the field, and drives it away from between the pole-horns.

Compared with synchronous motor generators and rotary converters, asynchronous motor generators are simpler and easier to operate, but their efficiency is lower

In a synchronous converter system there are two electromotive forces to be distinguished—the impressed and the counter The difference between these two is due to the reactance of the circuit, which depends on the phase of the currents and the excitation.

The first depends on the generator; the second on the field excitation. A converter can be made to take leading or lagging currents by changing the field excitation. By properly proportioning the field a converter can be made to run practically non-inductively at all loads

Many rotary converters are compound-wound, and the windings so divided that at no load the machine is under-excited, and at full load over-excited, the excitation increasing with the load To run rotary converters satisfactorily the transmission lines must contain a certain amount of inductance, too much inductance decreases the power factor and the stability of the system Rotary converters can be designed to give a power factor of approximately unity, from half-load to 50 per cent overload, and this is very beneficial in reducing the size of the high-tension feeders Compared to continuous currents for the same efficiency, the current carried is inversely proportional to the power factor, and hence the amount of copper required is inversely proportional to the square of the power factor

CHAPTER II

MOTORS

Before proceeding to discuss the third system of electric traction we will consider the continuous-current motor and its method of control.

In the early days of electric traction the speed used to be controlled by putting a resistance in series with the motors, so as to decrease the current passing through them. This method was exceedingly wasteful of power, and has now given way to what is known as the "series-parallel" control, one of the chief advantages of which is the large torque which can be obtained at starting by putting the motors in series.

The starting torque of a continuous-current motor is proportional to the current through the armature, to the number of conductors on the armature, and to the magnetization. Thus, for any given motor it is directly proportional to the current, and the voltage has no effect In the series-parallel method of control, by putting the motors in series when starting, the largest possible current through each armature is obtained, and consequently a large torque is produced. If the motors were in parallel, and the same amount of current were used, the current through each motor would be halved, with a like decrease in the torque, while the power used would be precisely the same as in the first case.

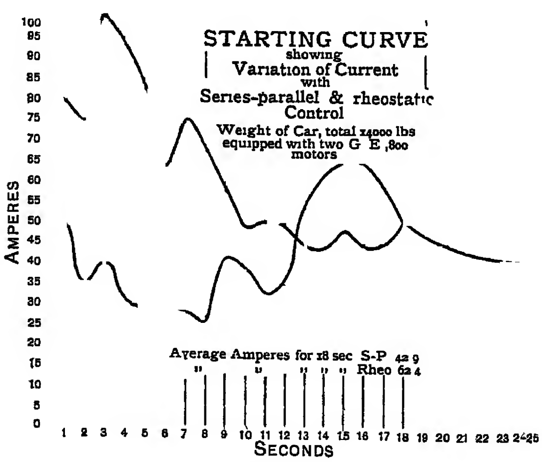

Fig 1235

The original difficulty due to arcing and burning at the contacts is now prevented by means of a strong magnetic "blow-out" Reversing the motors is done by means of a separate switch, with an interlocking arrangement which prevents the motors being reversed, except when the controller is in the "off" position.

The saving resulting from this system is shown in fig. 1235. It may be anything from 30 per cent to 60 per cent, depending on the conditions of the service and the skill with which the controller is handled. It has been found that with ordinary work, even where the stops are numerous, approximately 70 per cent of the energy taken from the line can be employed in useful work.

From the above description and diagram it will be seen what an important rôle the series-parallel control plays, particularly when distances between stops are short, and when rapid acceleration is important.

Wherever stops are frequent acceleration plays a most important part, in fact the success of electricity as a motive power on tramways, and especially on metropolitan railways, is very largely due to the high rate of acceleration which it is possible to obtain by its use. In order to maintain a high schedule speed with stations which are close together, the acceleration must be large, otherwise much time is wasted, and it is impossible to reach any speed. A comparison of the actual results obtained, shows that on the Metropolitan and District Railway line in London the steam locomotives accelerate at the rate of about 6 inches per second per second, as against approximately 18 inches on the elevated electric railways of Chicago, Brooklyn, Boston, &c

For a given average speed, the greater the acceleration the less the maximum speed need be

Experiments made by the General Electric Co. of Schenectady, with electric motor-cars and locomotives on an experimental track, have shown that it is possible to reach a speed of 30 miles per hour in ten seconds, starting from a stand-still. This means an average acceleration of about 4 feet per second per second. The acceleration on the Central London Railway is 12 inches per second per second, and that proposed to be used on the District when it is electrically equipped is 18 inches per second per second. With equipments supplied by Messrs Dick, Kerr, & Co to the Liverpool Overhead Railway, an acceleration of 36 inches per second has been reached. A suitable mean value must of course be taken, as the starting currents increase very largely with increased acceleration, and beyond a certain point the advantages gained by rapid acceleration would be more than annulled by the greatly increased capital required for the much larger generating and transmitting plant

As regards the weights to be hauled on the metropolitan electric railways, the figures given in the table below may prove of interest

Approximate Total Train Weights per Passenger carried for Various Lines

	Per Passenger
Central London Railway	930 lbs
Waterloo and City Railway	1100 „
City and South London Railway	460 „
Liverpool Overhead Railway	760 „
Metropolitan Elevated Railway (Chicago)	960 „
Metropolitan and District Railway (London)	800 „
Nantasket Beach Railways	700 „
Lecco-Sondrio Railway (Ganz system)	3250 „

The continuous-current motors with series-parallel control are particularly efficient during acceleration, because a considerable portion of this can be run on the motor curve with resistances entirely cut out, and an efficiency of 85 per cent maintained.

The series motor can always give a torque much in excess of the service demand without sacrificing any running qualities at light loads. Figs. 1236 and 1237 give some of the characteristics of a standard traction

motor. The series motor has no fixed maximum speed, this depending entirely upon the rating of the motors and the load. Cars, when stops are frequent, seldom run at their maximum speed, and thus have a higher speed in reserve, which enables them to make up for lost time should this become necessary

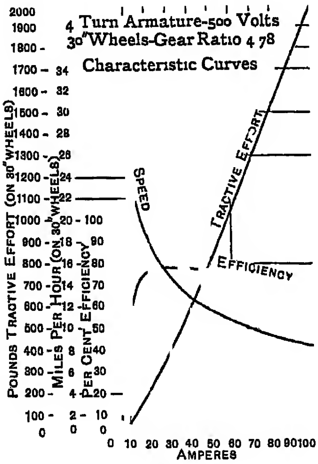

Fig 1236

Rating of Motors for Railway Work.—The rating of motors for railway work, as distinguished from tramway work, and the size of motor which must be adopted in any particular instance, are questions which must be most carefully considered in each individual case. In tramway work, at least as far as this country is concerned, the maximum speed is limited by the Board of Trade to 8 miles an hour This limit in some cases has been extended to 12 miles an hour, and stoppages are frequent. In railway work, the size of motor to be chosen will vary between very large limits according to the service to be operated. From experience which has been gained so far, both in Europe and America, it would appear that the only way to absolutely satisfactorily determine the type of motor to be used, is to design the motor as near as possible to the required conditions, and to mount the motor on a car, and operate the same at various schedules, and with given distances between stops, and with a given acceleration and average speed. The motors should then be run until they have obtained their maximum temperature, that is to say, until the temperature of the motor remains constant. The design of motors can, of course, be calculated so that they will very nearly fulfil the requirements imposed, but before they are definitely adopted, they should be submitted to a trial somewhat similar to the one described above. The shorter the distance between stops, and the heavier the train service, the greater the importance of rapid acceleration, and under such circumstances the question of attaining as high an average speed as possible between stations is of the greatest importance. It is evident that there are limits to the amount of acceleration which it is desirable to use, for not only must the comfort of the passengers be considered, but very high rates of acceleration would be so expensive, owing to the size and much greater cost of the motor and generating plant, as to be impossible to adopt. What this limit is, depends on the conditions that obtain in each individual case.

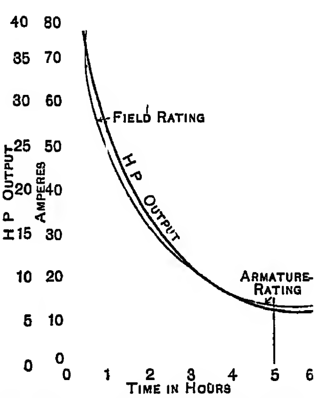

Fig 1237 —Characteristic Curves of Series Motor for Traction

Theoretically, the smallest energy consumption will be that of a train which accelerates up to a certain point, at which the power is then cut off, and which will then reach the end of its journey by coasting, without putting on the brakes. These conditions are, however, never realized in practice.

The run between stations may be divided into the following periods:—

(1) Acceleration up to maximum speed

(2) Constant speed, kept up by supply of power when the maximum speed has been reached

(3) Coasting

(4) Braking

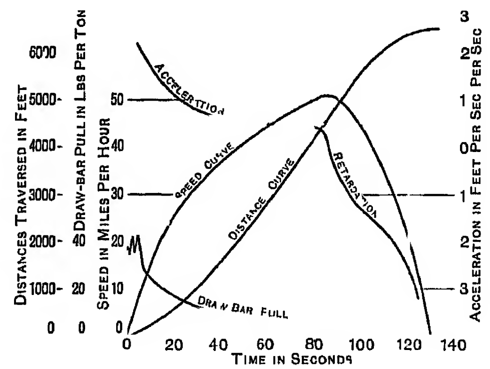

Fig 1238

As regards the question of braking, it may be stated here that with the air-brakes in use at present, the retardation varies between 3 feet and 5 feet per second per second, according to circumstances The following curves (figs 1238 and 1239), which have been constructed from average results which have been obtained on electric railways and on some steam railways, show the difference that exists been steam and electric traction, and the great advantages which the latter possesses in the rapid acceleration which is obtainable.

There are three ways of working electric trains, viz. —

(*a*) The locomotive system as originally used on the Central London Railway and the City and South London Railway.

(*b*) The motor-car as used on the City and Waterloo and the Liverpool Overhead Railways.

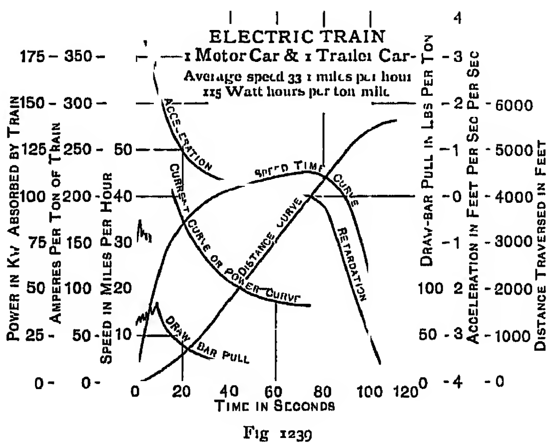

Fig 1239

(*c*) The multiple-unit control as used on the South Side Chicago Elevated and other roads.

Locomotive System.—This method of operating trains is borrowed from steam railroad practice. For the same weight of train the motors used would be larger than in the case of the multiple-unit system, and so their efficiency would be higher. Also the weight of the motor equipment could

be made less. An objection to its use is that to obtain the adhesion necessary for rapid acceleration the locomotive must be made very heavy, increasing the dead-weight. At the termini head and tail switching must be used unless a loop is employed.

Motor-Car System.—The use of a motor-car and trailers is a kind of cross between the foregoing and the multiple-unit system. In principle it is a locomotive which carries passengers, and so utilizes part of the load hauled to obtain adhesion between the wheels and track, being in this respect superior to a locomotive When two or more motor-cars are used, switching operations have not to be performed at the termini as for a locomotive.

Multiple-Unit System.—The multiple-unit system consists essentially in equipping two or more cars of a train as motor-cars, all of which can be operated and controlled from one point in the train It is usual for the end cars, at the front and back respectively, to be fitted with motors, other intermediate cars being also equipped if the length of the train requires it

Each motor-car has its own apparatus for collecting the current, and is provided with the regular controlling apparatus In this system, however, the controllers for each car are not worked by hand, but by some mechanical means Sprague and the General Electric Co use electricity, while the Westinghouse Co and the Schuckert Co use compressed air controlled by electricity The main principle, however, is the same in each case, all the motor controllers being operated in unison from one master controller

CHAPTER III

ALTERNATING-CURRENT ELECTRIC TRACTION

We now come to the third and fourth systems, which entail the use of alternating-current motors on the cars

Polyphase, and especially three-phase, motors have found practical application ever since the now historic three-phase power transmission from Lauffen to Frankfort, during the International Electric Exhibition of 1891. It was left to Messrs Brown, Boveri, & Co. of Baden, Switzerland, to first suggest, and finally successfully carry out, the practical equipment of the first commercial three-phase electric tramway at Lugano in 1894

The first railway to be equipped with three-phase motors was the Burgdorf-Thun line, also installed by Messrs. Brown, Boveri, & Co, and opened in July, 1899

Hitherto the reason for equipping lines on the three-phase system would seem to be that in all cases the current is generated by free water power, the current being transmitted at high tensions—10,000 to 20,000 volts. In all the lines installed by Messrs Brown, Boveri, & Co. the potential in any one phase of the contact line does not exceed 750 volts, the current from the feeders being transformed down to this pressure by static transformers situated along the line. Messrs Ganz & Co. have departed from this practice, and are using 3000 volts on their system on

the Lecco-Sondrio line. Messrs. Siemens and Halske and the Allgemeine Elektricitats-Gesellschaft of Berlin have used 10,000 volts on the experimental military railway between Berlin and Zossen

The properties of a three-phase traction motor differ considerably from those of a continuous-current series-wound traction motor The latter develops its greatest torque at starting, the only limit being the saturation of the fields and the current available. Unlike a series motor, the torque of a three-phase motor depends on other quantities besides the magnetization, the number of armature conductors, and the armature current. In the case of an induction motor the torque may be expressed as follows:—

$$T = \frac{M\,S\,r}{r^2 + L^2 S^2}, \text{ in which—}$$

T is torque in foot-lbs.,
M is proportional to the magnetization,
S is the slip,
r is the ohmic resistance of the rotor,
L is proportional to the self-induction of the rotor circuit

The slip is the difference between the number of cycles per second of the stator or exciting current and that induced in the rotor. The torque of a series-wound direct-current motor is $T = M\,N\,C_a$, in which N is the number of armature conductors, and C_a the current through the armature At starting, the slip of an induction motor will be equal to the frequency of the exciting current at full speed, when synchronism is nearly attained it will be very small, if absolute synchronism could be attained it would be zero.

At starting we can express the torque by $T = \frac{M\,r}{S\,L^2}$, as then the slip is very great as compared to r^2, which can be neglected

When full speed has been attained we can write $T = \frac{M \times S}{r}$, as then $S^2 L^2$ is very small as compared to r^2, and can be left out. Or in other words, at starting the torque is proportional to the rotor resistance and inversely proportional to the square of the self-induction of the rotor circuit, and at full speed it is proportional to the slip and inversely proportional to the ohmic resistance of the rotor. Therefore, whereas in a continuous-current motor the armature can be kept small by putting a large number of conductors in one slot, and the magnetizing current can be therefore reduced, the reverse is the case with a three-phase motor, where both the rotor and the stator windings have to be kept in as many separate coils as possible in order to reduce the self-induction.

The torque with an induction motor is dependent on the impressed line voltage, and it varies as the square of it This is due to the flux density of the magnetic field being relatively small, and the stator and rotor iron being much under-saturated, so as to reduce as far as possible the iron losses and magnetic leakage; the stator field is directly proportional to the pressure at the stator terminals.

With low speeds at starting the power factor of an induction motor is very low, and this necessitates a generating and distributing plant in which the volt-ampere capacity may have to be more than double the real watt capacity.

The air-gap has to be made very small, because the magnetizing current is proportional to it, and the power factor decreases rapidly as the air-gap increases. In some of the latest three-phase traction motors manufactured by Brown, Boveri, & Co., this gap has been reduced to 1 millimetre As compared to continuous-current series traction motors, this air-gap appears exceedingly small, $\frac{1}{4}$ inch and even more not being considered out of the way in their case. It is difficult even then to keep the armatures properly centred and prevent stripping of the armature coils, due to wearing down of bearings. If the rotor of a three-phase motor were to come in contact with the stator it would not only strip the coils off the rotor, but probably also off the stator, and thus spoil the windings of both, which would not happen in the case of a direct-current motor.

With a three-phase motor the starting torque is less than the maximum. The torque of a three-phase motor is increased by increasing the stator field, which depends upon the pressure at the stator terminals This increase has been effected by different means, as, for instance, by changing the stator connections at starting from Y to Δ, thus increasing the pressure in the proportion of 1 to 1 73, or by putting a boosting transformer in series with the stator.

The method almost universally adopted for speed regulation is to place a non-inductive resistance in the rotor at starting. The disadvantage of this method is that it is uneconomical. It is comparable to regulating a shunt-wound motor by putting a resistance in the armature circuit.

There is another method by which these losses at starting may be reduced, and which is comparable to the series-parallel control used with continuous-current railway motors This system has been called "concatenating", and Messrs Ganz speak of it as putting the motors in "cascade". This method, besides regulating the speed, ensures a large starting torque, but is only feasible when motors are used in pairs It appears to have been first brought out by Mr. Georges, of Messrs. Siemens & Halske, in Europe, and by Mr. Steinmetz, of the General Electric Co, in America. In this method, as shown in the diagram (fig. 1240), the two motors (which need not be the same in power or construction) are connected as follows —The stator of the first motor is switched directly on the line, the collector-rings on its rotor are in turn connected to the stator of the second motor, and the stator of the second motor is connected to a non-inductive resistance The motors thus connected will start with a large torque, but their maximum theoretical speed cannot exceed one-half of that of one of the motors directly connected across the line

When motors are connected thus in cascade at half speed, the slip of the rotor of the primary will be 50 per cent, and the cycles will be half the number of those supplied to the stator of the primary motor. The action of the primary on the secondary motor will tend to induce it to

rotate at synchronous speed and frequency. At half speed the frequency in the second motor will be half that in the primary. The speed of the rotor is proportional to the number of cycles, all being equal Therefore up to half speed the two motors could be in cascade. This would not be possible above half speed, as then the difference between the cycles induced in the rotor of the primary motor would be less than half frequency, and if this were connected to the secondary motor, would drive it at less than half speed, and hence, instead of acceleration, there would be retardation.

At high periodicities, the self-induction which is added by the stator

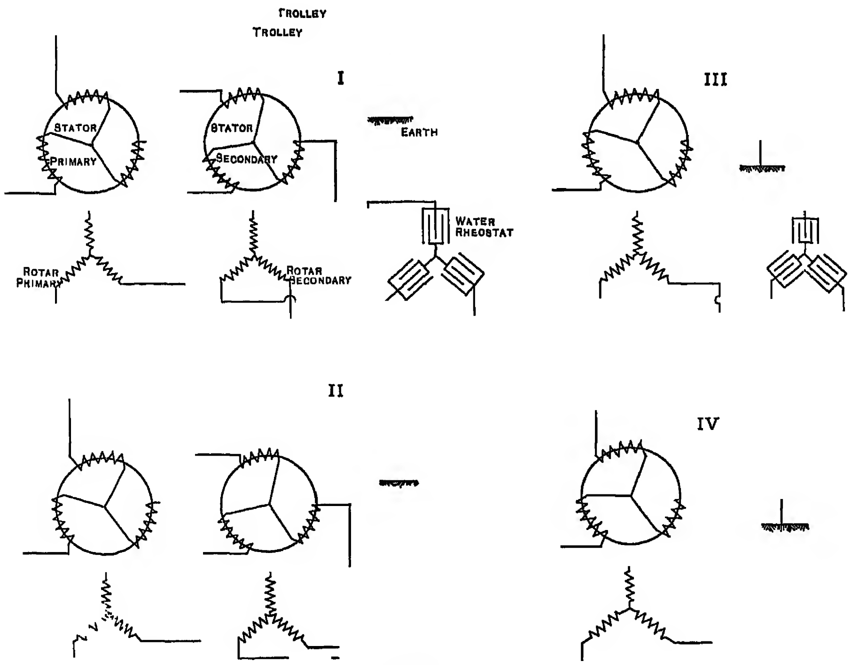

Fig 1240

of the second motor to the rotor of the first motor greatly reduces the torque of the latter.

The rotor winding of the first motor must be of fairly high resistance, in order to limit the current inflow and increase the electromotive force at the stator of the second motor, and if both motors are to be capable of running in parallel across the line, the ratio of the stator to the rotor windings must be unity.

As stated, in order for the motors to be interchangeable, the rotary of the primary would have to induce half-line voltage on the stator of the secondary motor at half speed. This would mean that the rheostats used would have to be built to stand the maximum full-line voltage. If this is not done, then the secondary motor can only be used at starting till half speed, and then must be cut out and become idle, except when slowing down, when it can be used for braking purposes from full to half speed During all other times this motor would be a useless dead-weight.

The advantages claimed for polyphase traction motors, and their corresponding disadvantages, are briefly set out side by side in the following table:—

Advantages.	*Disadvantages.*
1. Supply of current to the trolley lines is cheaper, as static transformers require practically no supervision.	1. Two or more conductors required to carry current to motors
2. Motor requires less attention and is more compact.	2. Difficult to obtain speed control equal in efficiency to that usual with continuous-current motors.
	3. Start not so quick or easy.
	4. Larger feeders for the same pressure, owing to wattless current
	5. Small air-gap likely to be source of trouble (owing to vibration).
	6. When rails are used as a return, their resistance (compared to that when continuous currents are used) increases in ratio of 6 or 8 to 1, according to frequency adopted.

On long lines where there are few stops the induction motor may be found very useful, especially if the current is generated by water-power. For suburban and metropolitan lines, where rapid acceleration is imperative, this type of motor is obviously unsuitable On mountain lines, where power can be returned for long periods at a time, three-phase motors have proved very successful.

The fact that power can be returned to the line by an induction motor is not as advantageous as would at first appear. It means that the motor will have to be built practically for continuous running, and will therefore be far heavier and more costly than would otherwise be the case. A railway motor is not designed on the same lines as an ordinary motor. The main object is to get the greatest possible torque per ampere of input A railway motor will be rated at four or five times the power that it would give out continuously. This is clearly shown in diagrams, figs 1236 and 1237. It is therefore an advantage for a motor not to be taking or giving out current continuously, as practically the only limit to the power of a given motor is the thermal limit.

The total amount of power supplied to the trains per ton-mile in cases like the Metropolitan District Railway is greater with three-phase induction motors than with continuous-current ones The best guarantee given from calculations (not from practical experience) by Messrs. Ganz & Co for three-phase trains on the District was 65 watts per ton-mile, which included an allowance of nearly 20 watts returned by braking; or, supposing that no such energy were returned, of 85 watts per ton-mile, as compared to 41.6 watts per ton-mile used on the Central London Railway.

A few remarks as regards the power plant and transmission line and sub-stations in the case of three-phase motor equipments are instructive.

1. The type of generating plant and transmission line is practically independent of whether rotary converters and direct-current motors or three-phase motors are used on the train. There would be sub-stations containing static transformers in either case.

2. In the United Kingdom, where the Board of Trade limits the drop in earth returns, more sub-stations would be necessary in the case of three-phase motors being used, for the following reasons:—

(*a*) The resistance of the return circuit, with alternating currents of 15 to 40 cycles per second, would be from six to eight times what it would be were a continuous current circulating in the return This is due to what is called the skin effect and the impedance of the rail return.

(*b*) Owing to the lower power factor, which probably on the average would not exceed 0.70, the current which the rails would have to return would be greater than if continuous currents were used

3. The station capacity with three-phase motors, owing to low power factor and larger amount of power needed to operate the trains, and larger starting power required, would have to be greater than where continuous-current motors are used on the line.

There are two new systems of alternating-current traction, which are now being tried in America, one system proposed by Arnold, the other by the Westinghouse Electric Manufacturing Co, and in Italy Dr. Finzi of Milan is experimenting in the same direction.

For an alternating-current system to compete successfully with continuous current as a means of operating railways, it is essential that only one supply circuit should be necessary, as is the case with continuous current, and that the characteristics of the alternating-current motor used should practically be the same as those of a continuous-current series-wound traction motor It follows from this, that the only alternating-current system which can be seriously considered is a single-phase alternating current. Motors for railway work must have variable speed characteristics—this condition is not complied with by polyphase motors. This difficulty has been met by the Westinghouse Co. of America by the reintroduction of a series-wound low-frequency single-phase alternating-current motor with a commutator. In the Westinghouse system, what practically amounts to a continuous-current series-wound motor is used, with a laminated magnetic circuit, and designed in such a manner that it can successfully receive alternating currents. The armature is short-circuited on itself across the brushes, and the brushes are set at an angle of 45 degrees from the neutral point. The field is connected across the supply circuit and contains the necessary controlling devices. This system is going to be installed on the Washington, Baltimore, and Indianapolis Railway, which is now under construction Single-phase alternating current will be supplied to the car at a frequency of 16.66 cycles per second, and at a pressure of 1000 volts.

The results obtained on this line will be watched with the greatest interest by all railway men, but it will, of course, take a considerable time

before sufficient experience has been gained to justify a railway adopting this system.

In the discussion which followed the reading of a paper on this subject before the American Institution of Electrical Engineers, Mr. Steinmetz clearly voiced the opinion held by all experienced traction engineers, when he stated "that alternating-current traction will only become feasible when the single-phase motor is developed to start with a maximum torque, the torque decreasing as the speed increases".

Dr. Finzi has carried out some very successful experiments with his single-phase motor on the Milan tramway system, but everything so far is in the experimental stage. The most promising system of all would seem to be that recently brought out by the Union Elektricitats Gesellschaft of Berlin. From the information to hand at present the motor used seems to fulfil all the necessary conditions for traction work, but the data that have so far been published concerning it are too scanty to enable any very definite opinion to be passed upon it.

The usual method adopted for conducting the current in railway work is that known as the third-rail, which generally consists of an ordinary steel rail, mounted on specially-designed insulators, spaced at intervals of from 4 to 12 feet apart. This rail is generally of special chemical composition, so as to reduce the electrical resistance as much as possible. In many cases two third-rails are employed, one positive and the other negative, the track-rails not being utilized for conveying the current. This method will be adopted on the Metropolitan District Railway. The third-rails can be constructed in sections, and arranged so that all the sections are dead except those under the train, this being adopted by means of a set of mechanically, magnetically, or electrically worked switches. The ordinary continuous third-rail can be, and often is, protected by means of an insulated troughing, having a slot in its side through which the current-collector enters, and makes contact between the third-rail and the car.

There are many objections to the use of a third-rail, and in a large number of cases it would be quite impossible to find room for its installation at termini and other places where there is a complicated net-work of track rails; even if space were available the danger to employees and the cost and difficulty of proper supervision render its use well-nigh impracticable. Everything points to the ultimate use of an overhead conductor from which the working current will be collected. The difficulties which would occur in negotiating tunnels can be more easily overcome than those which practically prohibit the use of third-rails in many situations.

The general trend of practice at the present day is towards the use of single-phase motors with a single overhead conductor.